

TM 71-10 FXN

**AIR FORCE FLIGHT DYNAMICS LABORATORY
DIRECTOR OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE OHIO**



**OPERATIONS MANUAL FOR THE AFFDL
DOPPLER RADAR AND ANTENNA POSITIONING SYSTEM**

H.W. PRINSEN, R.H. JARVIS and S.G. MARGOLIS
Cornell Aeronautical Laboratory, Inc.
CONTRACT NO. F33615-69-C-1018

EXPERIMENTAL ENGINEERING BRANCH
FLIGHT MECHANICS DIVISION

TECHNICAL MEMORANDUM TM 71-10 FXN

SEPTEMBER 1971

**Reproduced From
Best Available Copy**

20000503 123

Approved for public release;
distribution unlimited.

OPERATIONS MANUAL FOR THE AFFDL DOPPLER RADAR AND ANTENNA POSITIONING SYSTEM

H.W. PRINSEN, R.H. JARVIS and S.G. MARGOLIS

WARNING

OPERATORS ARE WARNED OF POTENTIAL DANGERS WHEN
OPERATING OR SERVICING THIS EQUIPMENT

HIGH VOLTAGES

RADAR INSTRUMENT (1100 V)

LARGE FORCES

SERVO SYSTEMS (22,000 LBS)

MICROWAVE RADIATION

TRANSMITTER ANTENNA
(500 MILLIWATTS/INCH²)

Approved for public release;
distribution unlimited.

SUMMARY

The operation of the Air Force Flight Dynamics Laboratory, 50 Megawatt Electrogasdynamics Facility (AFFDL, 50MW EGF), radar velocimeter is explained in this manual. Installation and maintenance instructions of the radar instrument and its special three-axis antenna positioning system are complete and in detail. Informative illustrations, parts lists, and references to other documentation are added, completing the operational description.

The velocimeter was developed under AF Contract Number F33615-69-C-1018, by Cornell Aeronautical Laboratory, Inc. (CAL), Buffalo, New York, 14221, as an experimental tool for use in determining the practicality of measuring plasma flow stream velocities up to 20k Ft/sec in the AFFDL 50MW EGF.

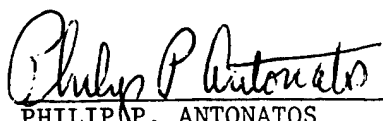
The program was administered by the Air Force Flight Dynamics Laboratory (AFFDL), Experimental Engineering Branch (FXN). Mr. J. P. Dolan served as project engineer until February 1969, and Mr. W. E. Alexander from February 1969 until completion. Special acknowledgment is given to AFFDL technical personnel for their invaluable assistance on the mechanical design and installation aspects of the antenna positioning system.

The principal co-investigators were Mr. H. W. Prinsen and Mr. B. R. Tripp. Mr. D. I. Kidder of CAL contributed significantly to the development and checkout of the system.

The program was initiated in September 1968 and was concluded in March 1971.

This memorandum, CAL Report Number UM-2712-E-2, was submitted by the authors in March 1971, for publication as an AFFDL technical document.

This memorandum has been reviewed and is approved.



PHILIP P. ANTONATOS

Chief, Flight Mechanics Division
Air Force Flight Dynamics Laboratory

TABLE OF CONTENTS

<u>Section</u>		<u>Page</u>
I	INTRODUCTION	1
	1.1 GENERAL DESCRIPTION	1
	1.2 POWER REQUIREMENT	2
	1.3 WEIGHT AND SIZE	2
	1.4 OPERATION HAZARDS	6
II	RADAR SYSTEM	7
	2.1 FUNCTIONAL DESCRIPTION	9
	2.2 TRANSMITTER PACKAGE	12
	2.3 TEMPERATURE SAFETY CONTROL CIRCUIT	15
	2.4 PHASE LOCK LOOP	17
	2.5 KLYSTRON POWER SUPPLY	21
	2.6 MIXER-PREAMPLIFIER	21
	2.7 RADAR SIGNAL PROCESSOR	24
	2.7.1 Main Doppler Amplifier	28
	2.7.2 Frequency Meter	28
	2.7.3 Detector and Schmitt Trigger	28
	2.7.4 Velocity Gating and Holding Circuit	32
	2.8 WIRING DIAGRAM	32
III	RADAR OPERATING INSTRUCTIONS	36
	3.1 TRANSMITTER SWITCH-ON	36
	3.2 TRANSMITTER LOCK-ON	38
	3.3 RADAR SIGNAL PROCESSOR SWITCH-ON	38
IV	ALIGNMENT, CALIBRATION AND CHECKOUT OF THE RADAR SYSTEM	40
	4.1 ANTENNA ALIGNMENT	40
	4.2 MICROWAVE FREQUENCY AND POWER TESTS	44
	4.3 SIGNAL PROCESSOR THRESHOLD ADJUSTMENT	44
	4.4 RADAR OUTPUT CALIBRATIONS	44
	4.4.1 Doppler Frequency Meter	44
	4.4.2 Digital Velocity Read-Out	45
	4.4.3 Doppler Signal Frequency of Occurrence	45
	4.4.4 Doppler Signal Duty Factor	45
	4.4.5 Doppler Signal Time History and Signal Amplitude	45
	4.5 SUMMARY OF RADAR OUTPUTS	46
V	ANTENNA POSITIONING SYSTEM	47
	5.1 SERVO POSITIONING MECHANISM	47

TABLE OF CONTENTS (Cont.)

<u>Section</u>	<u>Page</u>
5.1.1 Axial Servo Drive Assembly	53
5.1.2 Lateral Servo Drive Assembly	53
5.1.3 Vertical Servo Drive Assembly	53
5.1.4 Antenna Positioners	53
5.2 FUNCTIONAL DESCRIPTION OF THE SERVO SYSTEM	54
5.3 POWER DISTRIBUTION FOR ANTENNA POSITIONING SYSTEM	59
VI MECHANICAL INSTALLATION	63
6.1 COOLING OF EQUIPMENT	63
6.2 PROTECTION OF WIRING	63
6.3 SAFETY SWITCH INSTALLATION	63
VII ANTENNA POSITIONING SYSTEM OPERATING INSTRUCTIONS	66
7.1 SERVO CONTROL PANEL	66
7.1.1 Digital Indicators	66
7.1.2 Axis Positioning Controls	66
7.1.3 Circuit Breakers	68
7.1.4 Axis Limit Indicator Lights	68
VIII ALIGNMENT, CALIBRATION AND CHECKOUT OF ANTENNA POSITIONING SYSTEM	69
8.1 MECHANICAL ZERO POSITIONS	69
8.2 CALIBRATION OF DIGITAL POSITION READ-OUT	69
8.3 SERVO ALIGNMENT	70
8.4 ALIGNMENT OF SET-POINT POTENTIOMETERS	70
8.5 MECHANICAL ALIGNMENT	70
8.6 POSITION OUTPUTS	72
IX MAINTENANCE AND INSPECTION PROCEDURES	73
9.1 TRANSMITTER PACKAGE	73
9.2 WAVEGUIDE	73
9.3 GUIDE ROD MAINTENANCE	73
9.4 MACHINE SCREW JACKS	73
9.5 VERTICAL AXIS DRIVE SHAFT PILLOW BLOCK	73
9.6 AXIAL AXIS MITRE GEAR BOX	74
9.7 SERVO MOTORS	74
9.8 SERVO AMPLIFIER COOLING	74
9.9 WIRING HARNESS INSPECTION	74

TABLE OF CONTENTS (Cont.)

<u>Section</u>		<u>Page</u>
X	REFERENCES	75
<u>Appendices</u>		
I	RADAR PARTS LISTS	77
II	SERVO POSITIONING SYSTEM DRAWINGS, SUBASSEMBLIES AND PARTS LISTS	83
III	DIRECTIONS FOR THE INSTALLATION OF THE ANTENNA POSITIONING SYSTEM	93

LIST OF ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	Radar and Antenna Positioning System Installed for Checkout at CAL.	4
2	Radar and Antenna Positioning System Control Panels	5
3	Bistatic Radar Antenna Technique	8
4	Radar System Block Diagram	10
5	Location of Radar Subassemblies.	11
6	Transmitter Package Block Diagram.	13
7	Transmitter Package and Transmit Antenna	14
8	Temperature Safety Control Circuit	16
9	Temperature Safety Control Circuit Output Voltage Versus Klystron Flange Temperature	18
10	Phase Lock Loop.	19
11	27-MHz Line Driver	20
12	Block Diagram of Modified FEL 130A Synchronizer.	22
13	Detail of Radar Assembly with Antennas	23
14	Microwave Mixer and Preamplifier	25
15	Preamplifier Frequency Response.	26
16	Radar Signal Processor Block Diagram	27
17	Main Doppler Amplifier	29
18	Main Doppler Amplifier Frequency Response.	30
19	Detector and Schmitt Trigger	32
20	Velocity Gating and Holding Circuits	34
21	Radar Wiring Diagram	35
22	Radar Control Panels	37
23	Bistatic Antenna Geometry.	41
24	Antenna Alignment Tool	42
25	Antenna Alignment Technique.	43
26	Antenna Positioning System Elevation View.	49

(U) LIST OF ILLUSTRATIONS (Cont.)

<u>Figure</u>		<u>Page</u>
27	Antenna Positioning System End View.	50
28	Antenna Positioning System Plan View	51
29	Schematic and Wiring Diagram of Axial Axis Servo Channel.	55
30	Schematic and Wiring Diagram of Lateral Axis Servo Channel.	56
31	Schematic and Wiring Diagram of Vertical Axis Servo Channel.	57
32	AC and DC Distribution for Antenna Positioning Control System	61
33	Air Flow Diagram	64
34	Antenna Positioning System Control Panel	67
35	Servo Potentiometer Coupling for Axial and Lateral Channels	71

Section I

INTRODUCTION

1.1 GENERAL DESCRIPTION

The experimental doppler radar and antenna positioning system was developed by Cornell Aeronautical Laboratory, Inc., (CAL) for the U.S. Air Force Flight Dynamics Laboratory (AFFDL), Wright-Patterson Air Force Base, Ohio, under Contract No. F33615-69-C-1018.

The radar and antenna positioning system is intended for use as a diagnostic instrument for measuring gas flow velocity in the AFFDL 50-Megawatt Electrogasdynamics Facility, and for investigating radar backscatter characteristics of the hypersonic flow with variations in arc heater input parameters. The equipment is installed in the facility test chamber and control room.

The equipment is separated functionally into two assemblies: (1) the radar system for measuring flow characteristics, and (2) the antenna positioning system for remotely setting the location where the gas flow characteristics are measured. Listed below are the major sub-assemblies and their locations in the facility.

Radar System

(a) Transmitter Package	- Test Cabin
(b) Radar Antennas	- Test Cabin
(c) Radar Receiver Mixer-Preamplifier	- Test Cabin
(d) Transmitter (klystron) Power Supply	- Control Room
(e) Doppler Signal Processor	- Control Room
(f) Klystron Frequency Synchronizer	- Control Room

Antenna Positioning System

- | | |
|---|----------------|
| (a) Mechanical Assembly for Positioning System, including Servomotors | - Test Cabin |
| (b) Position Control Panel | - Control Room |
| (c) Servoamplifiers and Power Supplies | - Control Room |

Systems parameters are summarized in Table 1.

The servomotors, transmitter package, and receiver preamplifier are mounted with the mechanical structure in the test cabin. They are operated remotely via control panels located in the facility control room. The equipment located in the test cabin was designed to operate properly in the vacuum environment existing under normal operating conditions. Circulating cooling air must be supplied to some units.

The equipment as installed at CAL for preliminary evaluation tests is shown in Figure 1. Two main support brackets were temporarily bolted to two vertical beams of the building structure. The main horizontal antenna support beam could move up and down along the two vertical guide rods shown in the photograph. The antennas were mounted to carriages which could move parallel and perpendicular to the main support beam. The antenna position controls panels and servoamplifier chassis are mounted in the control rack at the left and the rack at the right contains the radar equipment. The oscilloscope shown in the photograph was used to display signals for test purposes and is not part of the equipment delivered under this contract. The location of controls and indicators on the control panels are shown in Figure 2.

1.2 POWER REQUIREMENT

The electrical power required to operate the equipment is 115-VAC single-phase at 4.5 kW.

1.3 WEIGHT AND SIZE

The weight of the antenna positioning system without the radar electronics totals 1546 pounds.

The width of the mechanical assembly is 143.5 inches, height 120 inches and maximum extended depth without antennas 39 inches. The

Table I
RADAR AND ANTENNA POSITIONING SYSTEM PARAMETERS

RADAR SYSTEM	ANTENNA POSITIONING SYSTEM
<p>RADAR FREQUENCY 35 GHz (STABILIZED)</p> <p>TRANSMITTED POWER 100 mW</p> <p>ANTENNA APERTURE 22-INCH DIAMETER</p> <p>COLLIMATED BEAMWIDTH AT FOCAL POINT 0.7-INCH DIAMETER</p> <p>NOMINAL ANTENNA FOCAL LENGTH 45.6 INCHES</p> <p>FOCUSING RANGE* 40 TO 61 INCHES</p> <p>MINIMUM DETECTABLE NORMALIZED (σ / λ^2) RADAR CROSS SECTION -88 dB (FOR 0 dB SIGNAL/NOISE)</p> <p>RADAR SAMPLE VOLUME 0.2 INCH³ (-3 dB)</p> <p>DOPPLER SIGNAL BANDWIDTH 100-700 kHz</p> <p>DOPPLER MEASUREMENT 5% OR BETTER (FOR SIGNAL/NOISE > 6 dB AND DUTY FACTOR > 0.2%)</p> <p>ACCURACY</p> <p>RADAR OUTPUTS</p> <p>MEAN DOPPLER VELOCITY</p> <p>MEAN DOPPLER SIGNAL DUTY FACTOR</p> <p>MEAN DOPPLER SIGNAL AMPLITUDE</p> <p>MEAN FREQUENCY OF OCCURRENCE OF DOPPLER SIGNAL</p> <p>DOPPLER SIGNAL (UNDETECTED)</p> <p>DIGITAL FLOW VELOCITY INDICATOR</p> <p>INDICATING NEAREST 0.1 kft/s</p>	<p>POSITIONING RANGE OF RADAR RESOLUTION CELL</p> <p>VERTICAL: 1 INCH BELOW TO 22 INCHES ABOVE FLOW AXIS</p> <p>HORIZONTAL: 21 INCHES EITHER SIDE OF FLOW AXIS</p> <p>AXIAL: 0 TO +12 INCHES PARALLEL WITH FLOW AXIS</p> <p>CONTROL ACCURACY +0.1 INCH (EACH AXIS)</p> <p>SLEWING SPEED 1 INCH/SECOND (EACH AXIS)</p> <p>POSITION OUTPUTS 10 INCHES = 1.0 VOLT (EACH AXIS)</p> <p>DIGITAL POSITION INDICATORS INDICATING NEAREST 0.1 INCH</p>
<p>* RANGE OVER WHICH ANTENNA CAN BE FOCUSED BY MOVEMENT OF THE ANTENNA FEED.</p>	

THIS
PAGE
IS
MISSING
IN
ORIGINAL
DOCUMENT

4/5

radar and antenna positioning system electronics can be mounted in standard 18-inch racks, except for the vertical driver servoamplifier which mounts separately on the rack floor. A total rack space of 74 inches is required.

1.4 OPERATION HAZARDS

The operator is warned of potentially dangerous voltages (up to 1100 volts) existing at the microwave transmitter. Standard precautionary measures should be observed in servicing or disconnecting any circuits associated with the transmitter or the transmitter power supply.

At the focal point of the transmitting antenna, approximately 50 inches away from the reflector along the central axis of the antenna, the incident microwave power density may reach a level as high* as 500 mW/in². The high power density is confined to a small volume, beyond which the power density drops rapidly with increasing distance. It is important, however, to avoid exposure of the body to the power density existing at or near the focal point of the transmitting antenna.

The servodrives used to position the antennas are capable of exerting large forces. The vertical drive system is capable of exerting a force in excess of 20,000 pounds. Operators must therefore exercise care when operating the system with personnel present in the test cabin or in the immediate vicinity of the mechanical drive mechanisms. It is recommended that a safety switch be installed in the test cabin which can be used to switch off all power to the servodrives when servicing this portion of the system. This switch is discussed in subsections 5.2 and 6.3.

*The recommended maximum safe dosage of human irradiation is 75 mW/in² (Non-Ionizing Radiation, Vol. 1, No. 1, June 1969, pp. 5-6).

Section II

RADAR SYSTEM

The technique used in the radar for measuring gas flow velocity makes use of the doppler effect. Assuming the flow is ionized, the radar backscatter would result from spatial variations of the electron number density. The doppler frequency shift of the backscatter is believed to be caused by motion of the electron number density irregularities through the radar sample volume. The doppler shift is proportional to the velocity of the flow if it is assumed that the positive ions, and thus the electrons bound to the ions by electrostatic forces, move with the velocity of the neutral molecules in the gas stream. The frequency shift is detected in the radar receiver and converted to a voltage proportional to velocity.

The backscattered radar signal is expected to be randomly interrupted. Such characteristics were observed at X-band in an experimental investigation conducted by CAL (Reference 1) under Air Force Contract No. F33615-67-C-1964 in which doppler radar measurements were made on the free stream in the 50-MW EGF. To minimize effects of such interruptions on the velocity measurements, a special radar signal processor was designed and incorporated in the present system which should make the doppler measurements relatively insensitive to such effects. The signal processor, in addition to measuring doppler velocity, measures mean frequency of interruptions, average duty factor, and mean amplitude of the doppler signal. The processor provides low-frequency analog voltages for direct recording on strip charts or magnetic tape. Mean velocity is indicated by a direct digital read-out on the Antenna Positioning Control Panel.

The radar system provides a high degree of spatial resolution to permit localized measurements of radar observables within the ionized stream. The 35-GHz frequency of operation was chosen so that a small sample volume could be effected through the use of a bistatic focused beam antenna technique. Each antenna provides a collimated cylindrical beam approximately 2 wavelengths in diameter (-3 dB points) by 20 wavelengths in length at the focal point (one wavelength, $\lambda = 0.34$ inch). With two antenna beams intersecting at their focal points as shown in Figure 3, a radar sample volume of approximately $4.18 \lambda^3$ was obtained in the system checkout tests performed at CAL.

A functional description of the radar system, detailed descriptions of the components, and schematic diagrams are presented in the next section.

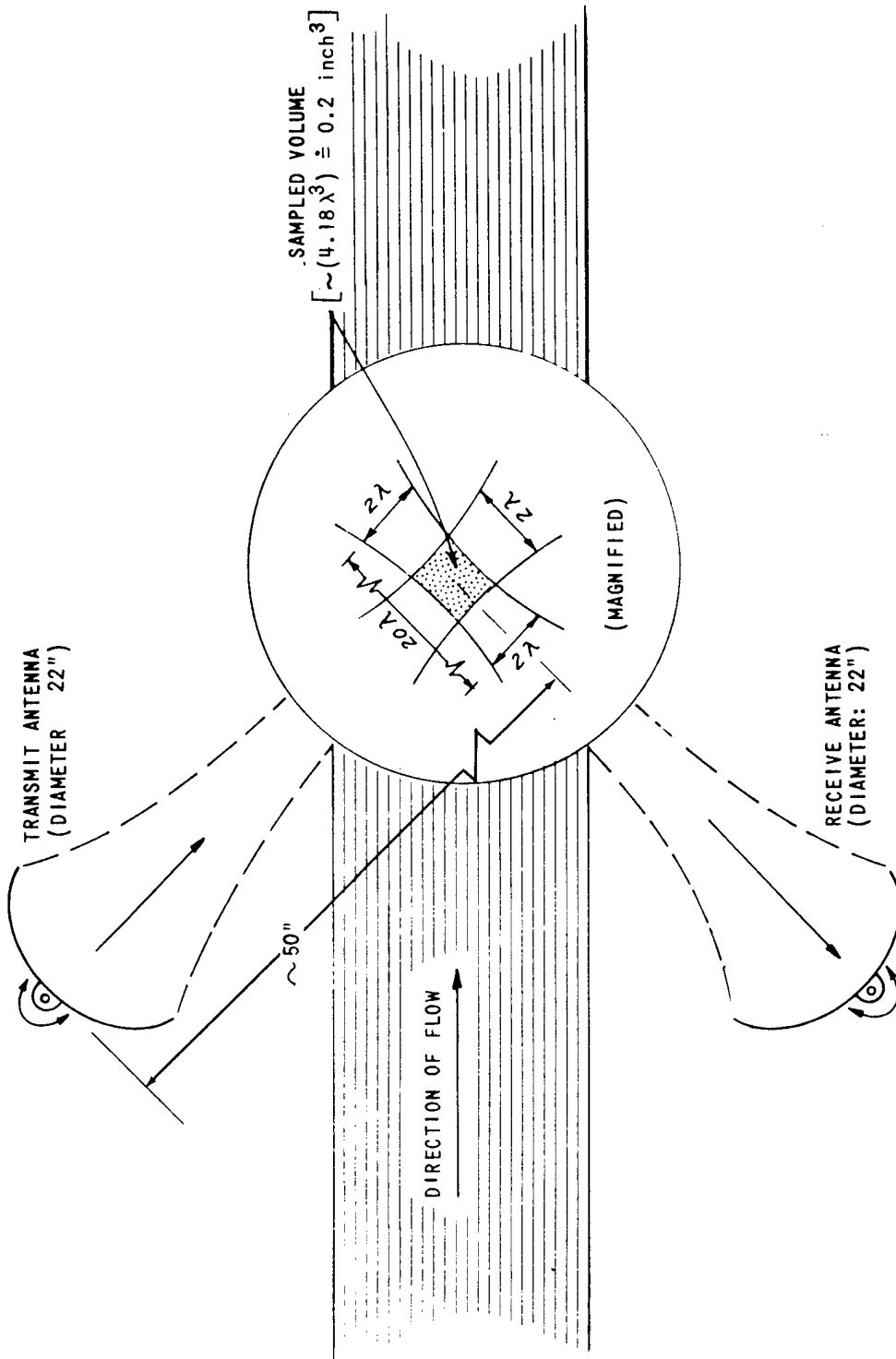


Figure 3 BISTATIC RADAR ANTENNA TECHNIQUE

2.1 FUNCTIONAL DESCRIPTION

For the discussion which follows, reference is made to the block diagram of Figure 4. For orientation of the reader, locations of radar subassemblies are shown in Figure 5. Parts lists for the radar subassemblies are provided in Appendix I.

The transmitter is a CW klystron oscillator operating at a frequency of 35 GHz. The klystron frequency is stabilized by means of a phase lock loop which provides closed-loop phase control of the klystron output. Such phase control results in a signal having a high degree of spectral purity.

The klystron is connected through an isolator and a 20-dB directional coupler to the transmitting antenna. The isolator is used to reduce effects of transmission line reflections on the klystron frequency stability. The 20-dB coupler provides approximately 1 mW of microwave power to the mixer crystals in the receiver mixer/preamplifier. This microwave signal serves as a coherent local oscillator for the receiver mixer.

The receiver antenna collects the backscattered signal from the scatterers within the radar sample volume. The received signal is heterodyned or mixed with the above local oscillator signal in the receiver mixer and the resulting difference frequency signal (doppler signal) is amplified in the receiver preamplifier and main doppler amplifier. The bandpass characteristics of these amplifiers are tailored to reject DC and the lower frequency doppler signals which correspond to returns from stationary or slowly moving targets and to pass the higher frequency doppler signals associated with the hyper-velocity flow. Such filtering provides a high degree of rejection of extraneous radar signals from tunnel wall, model support struts and from other nonmoving objects in the test cabin.

The frequency meter provides a DC voltage which is proportional to the doppler frequency of the incoming signal. A gate inhibits the output of the frequency meter when the signal level is too low for accurate velocity determination. The gate is enabled by a Schmitt trigger which is activated whenever the amplitude of the doppler signal exceeds a preset threshold level.

A holding circuit retains the latest sample of velocity output which is updated whenever the doppler signal amplitude exceeds a preset threshold setting. The gating technique was incorporated because previous tests, as explained earlier, showed that the radar backscatter signal is randomly interrupted with the interruptions depending upon arc heater operating parameters. The threshold is normally set slightly above the system noise level.

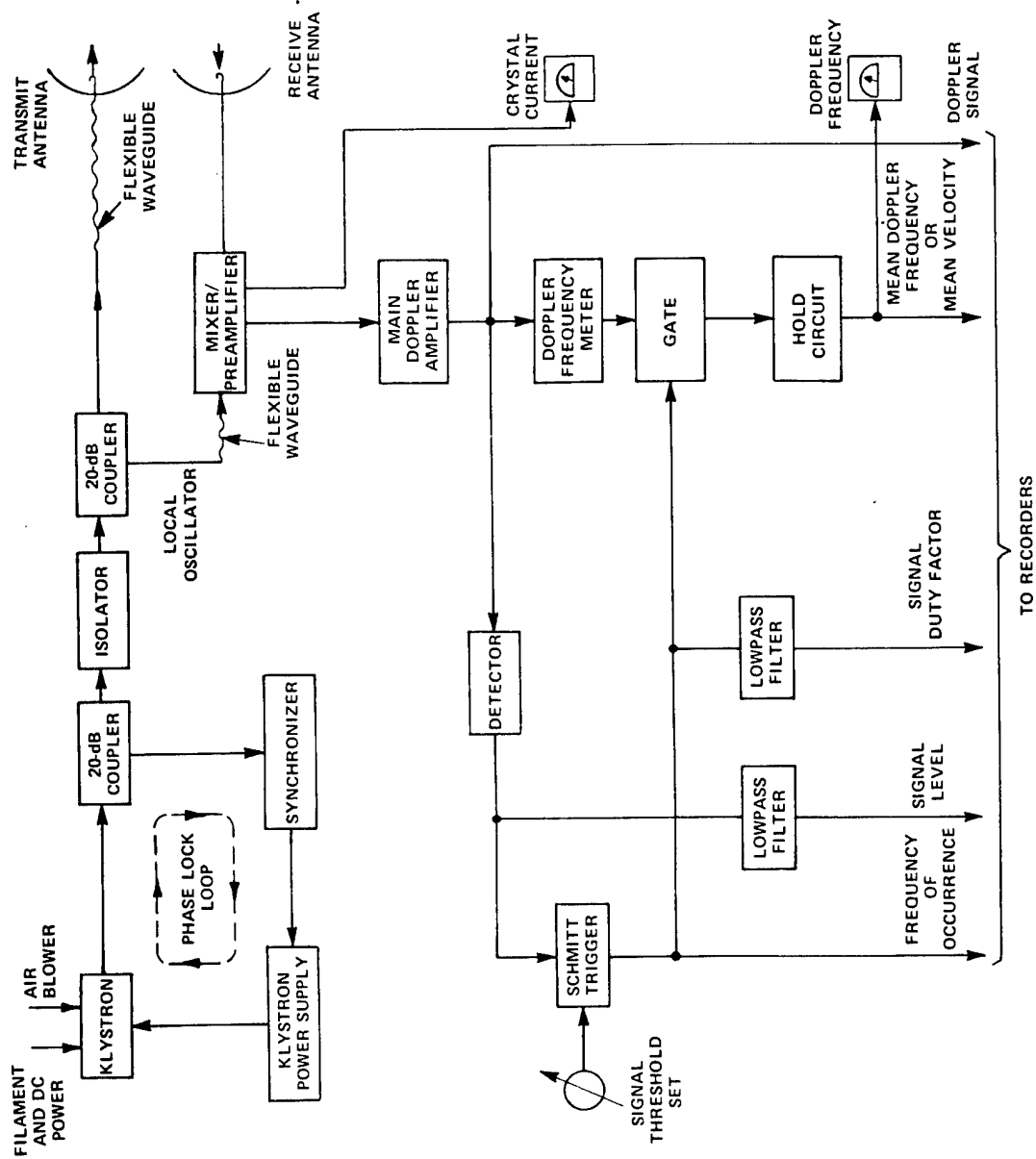


Figure 4 RADAR SYSTEM BLOCK DIAGRAM

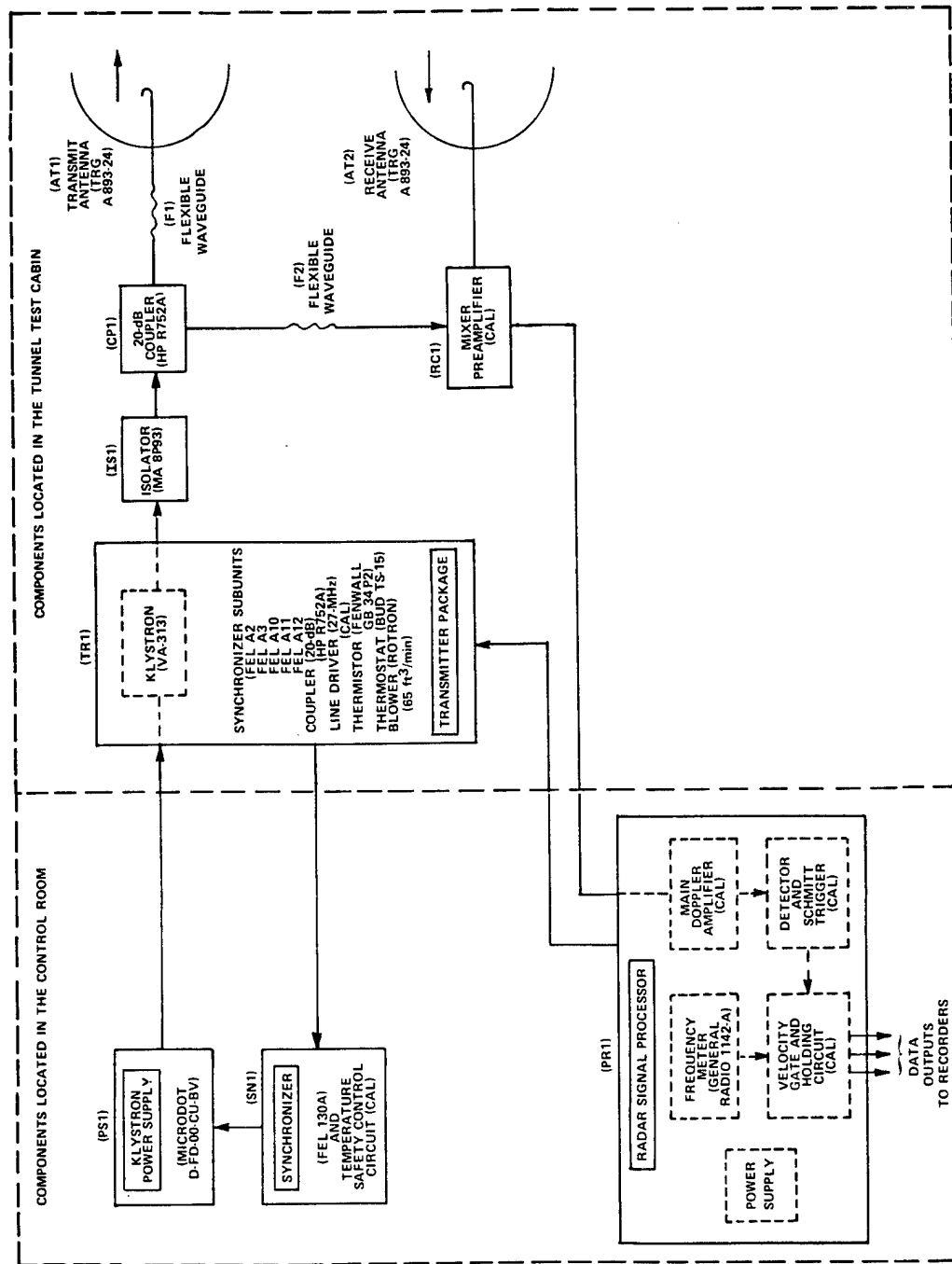


Figure 5 LOCATION OF RADAR SUBASSEMBLIES

The output of the Schmitt trigger after filtering is proportional to the average duty factor of the doppler signal interruptions. Outputs are also provided to permit measurement and recording of the doppler signal time history, the frequency of occurrence of signal interruptions (i.e. Schmitt trigger output), doppler signal amplitude (i.e. detector output). A direct digital read-out of doppler velocity is provided on the radar panel.

2.2 TRANSMITTER PACKAGE

A block diagram of the transmitter package is shown in Figure 6. In addition to the K_a-band klystron (Varian Type 313), it contains modules U₁ to U₆ which form part of the phase lock loop. The operation of the klystron phase lock loop is described in subsection 2.4.

The transmitter package is hermetically sealed and mounted in back of the transmitting antenna. The location of the transmitter package is shown in Figure 7. The klystron provides approximately 200 mW of RF power. Protective diodes D₁ and D₂ (Figure 6), connected between the klystron reflector and cathode, prevent the reflector from going positive with respect to the cathode. A blower inside the package provides forced-air cooling for the klystron tube.

Heat transfer from the transmitter package is by radiation and conduction through the connecting waveguide and mounting straps, and by cooling air which is circulated through the package. A corrugated surface is provided to increase radiation efficiency. Cooling air is required at a rate of 5 ft³/min; cooling requirements are discussed in greater detail in subsection 6.1. For purposes of system checkout under normal room conditions, the transmitter package can be operated without cooling air for periods of one-half hour or less.

Protection is provided against interruption of the cooling air by two independently acting temperature sensors. A thermistor sensor (M1) in a bridge circuit measures the temperature at the klystron output flange. When the temperature reaches 72°C, a trip circuit is activated which switches off the klystron power supply. A thermostat (M2) is provided for backup protection and is set to operate at approximately 90°C. The electronic trip circuits are located in the klystron synchronizer unit.

It is possible that heat radiated from models in the flow can effectively raise the transmitter case temperature to an unacceptable level. It is therefore recommended that a heat shield be placed in front of the transmitter package for added protection.

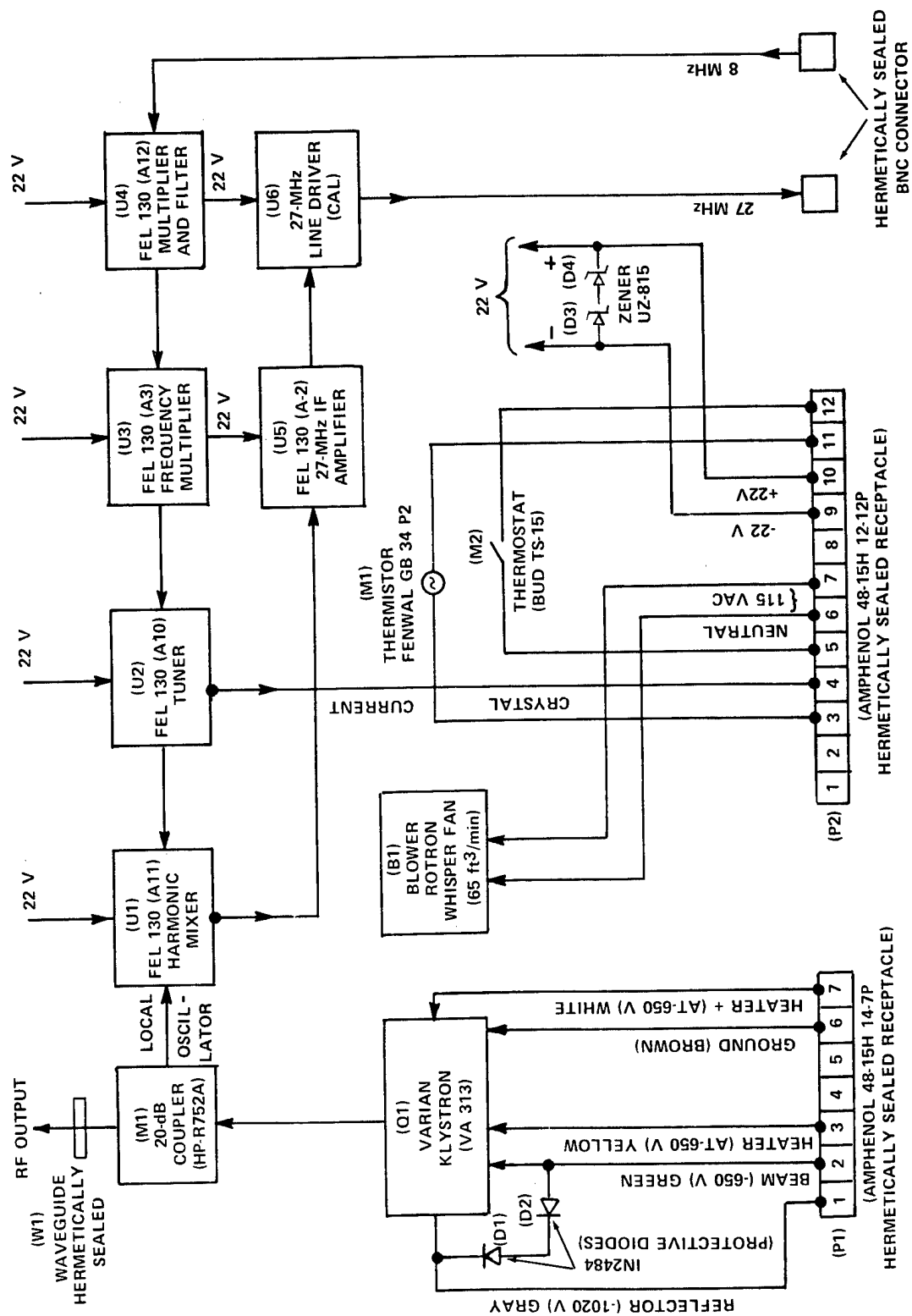


Figure 6 TRANSMITTER PACKAGE BLOCK DIAGRAM

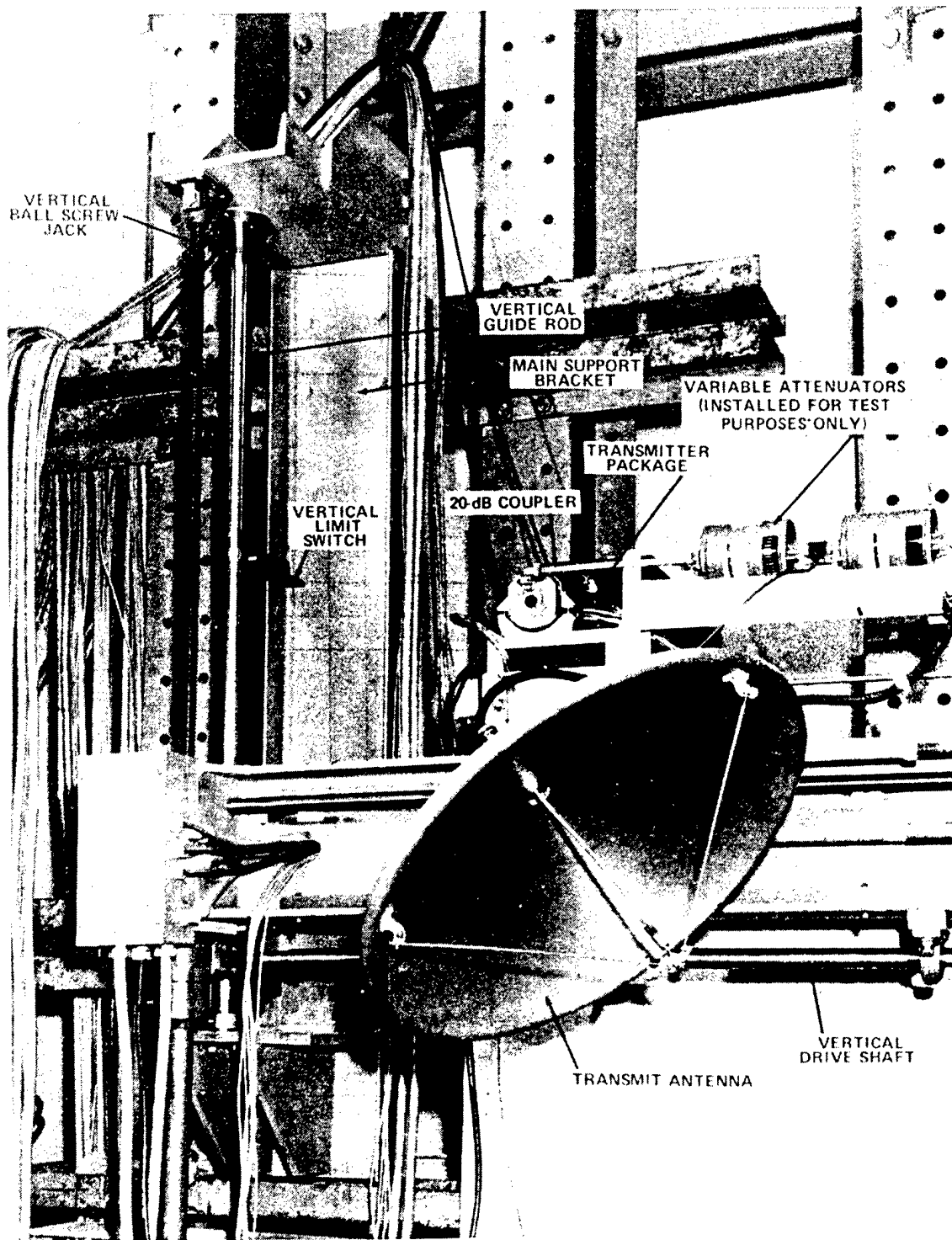


Figure 7 TRANSMITTER PACKAGE AND TRANSMIT ANTENNA

A DC voltage of 22 volts is required to power the phase lock loop modules U₁ - U₆. Zener diodes D₃ and D₄ protect the 22-volt line against voltage surges.

Shielded cables with polyethylene insulation and Amphenol type 48 hermetically sealed connectors are used to supply electrical power to the package. The cables and connectors were tested at CAL and exhibited no corona or arcing effects for pressures corresponding to 200,000 ft altitude and for operating voltages up to 1500 volts DC. The latter is the maximum operating voltage of the klystron. Hermetically sealed BNC connectors are used for the IF connections. The transmitter output waveguide is hermetically sealed with a waveguide window flange.

2.3 TEMPERATURE SAFETY CONTROL CIRCUIT

The klystron can operate at a maximum safe flange temperature of 100°C. The temperature safety control circuit automatically switches off all power to the klystron before this temperature condition is reached. A schematic diagram is shown in Figure 8. A sensing thermistor which is cemented to the klystron flange forms part of the feedback circuit of the operational amplifier A₁. When the temperature increases, the thermistor resistance decreases and the output of A₁ goes positive. When the output of A₁ exceeds the threshold voltage at terminal 2 of the voltage comparator A₂, the output of A₂ switches from a high voltage to a low voltage. Transistor Q₁, which was held in saturation by the high output voltage of A₂, is cutoff and relay RL₁ is deenergized. When this occurs, the "normally closed" contacts of the relay close. This action in turn activates a trip circuit internal to the klystron power supply which switches off all klystron power. The threshold voltage at terminal 2 of A₂ can be adjusted by potentiometer R₄. It is set so that tripping occurs when the klystron output flange reaches a temperature of 72°C. The power to the klystron can only be restored when the temperature has dropped below this level and the klystron power supply has been manually turned off and then on again. A thermostat mounted in the transmitter package is provided for backup protection. When the klystron flange temperature reaches 90°C, the thermostat contacts close, in turn switching off transistor Q₁ and relay RL₁ of the circuit just discussed.

The temperature safety control circuitry is located inside the Frequency Engineering Laboratories (FEL) synchronizer unit Type 130A. The output of Amplifier A₁ (Figure 8) can be used to monitor the klystron flange temperature. Terminals are brought out for this purpose

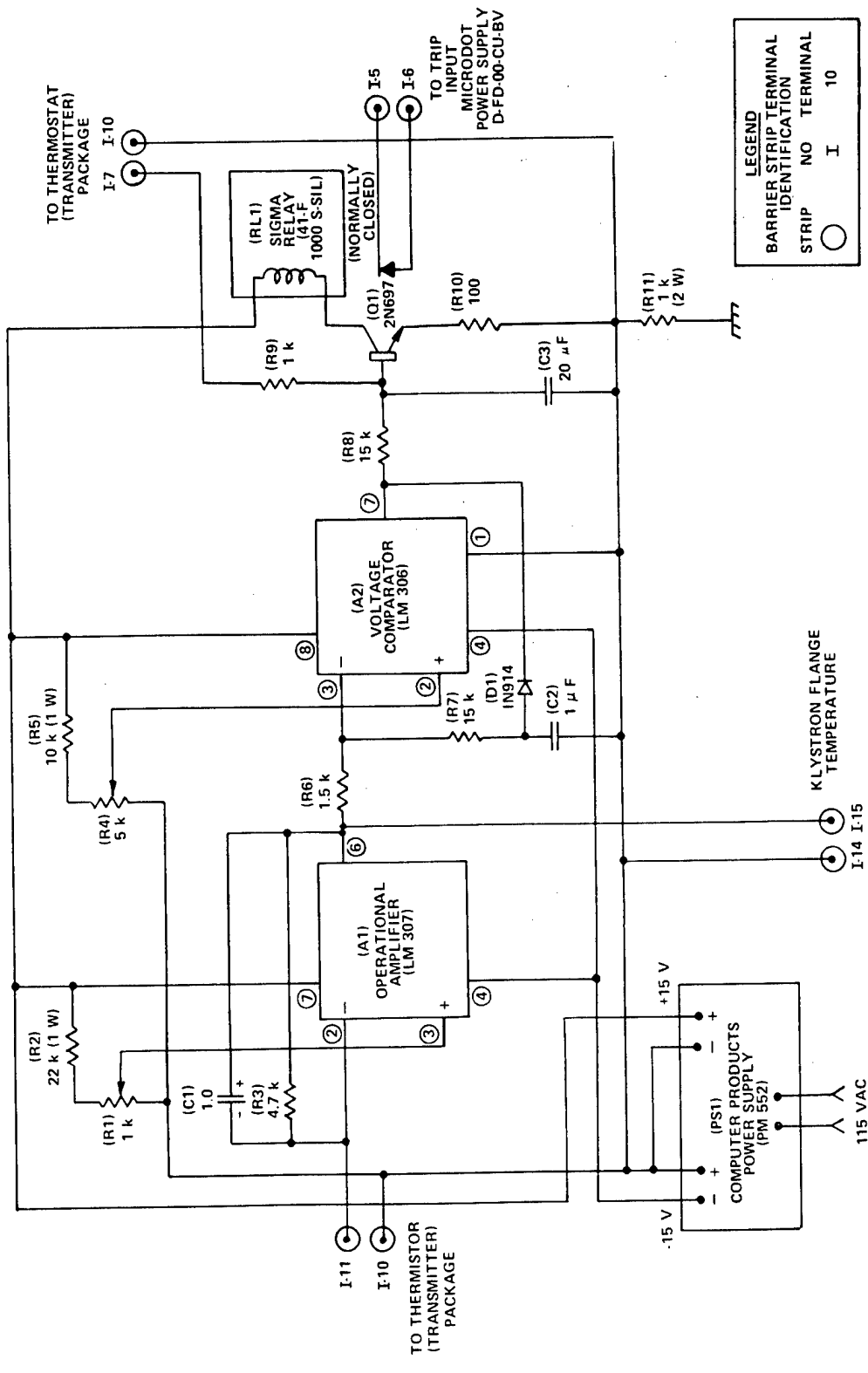


Figure 8 TEMPERATURE SAFETY CONTROL CIRCUIT

on the synchronizer chassis. A calibration curve showing temperature versus output voltage is given in Figure 9.

2.4 PHASE LOCK LOOP

This paragraph describes briefly the operation of the phase lock loop, which synchronizes the klystron frequency to a stable crystal-controlled source. The phase lock operation is performed by a Frequency Engineering Laboratories (FEL) Type 130A synchronizer unit. A simplified block diagram is shown in Figure 10. For a detailed description of operation, the reader is referred to the instruction manual supplied with the equipment (Reference 2).

The reference frequency for the phase lock loop is derived from a stable, but tunable, crystal-controlled 8-MHz oscillator. This signal is multiplied in a series of harmonic multipliers, generating a comb of frequencies, 8 MHz apart, centered at 432 MHz. These frequency components are mixed with a sample of the microwave signal in a harmonic mixer. The output of the mixer is amplified in an IF bandpass amplifier centered at 27.365 MHz. By tuning the crystal-controlled oscillator, the frequency comb can be shifted slightly so that one of the harmonic mixer outputs is at the IF center frequency. A phase detector compares the phase of the IF signal with the phase of the stable crystal-controlled 27.365-MHz reference oscillator. The phase detector produces an error voltage proportional to the phase difference of the two signals. This error voltage is fed back to the klystron reflector (via the klystron power supply). This process phase locks the klystron frequency to the reference frequency which was initially derived from the 8-MHz signal. As noted above, "locking" is achieved by manually adjusting the frequency of the 8-MHz oscillator. An indicator light on the front panel of the unit signals the operator when "phase lock" occurs.

The synchronizer requires a sample of the microwave signal output from the klystron. This is supplied through the 20-dB coupler M1 to the harmonic mixer U1 as shown in Figure 6. To eliminate the need for a long and lossy microwave transmission link between the transmitter (test cabin) and the synchronizer unit (control room), some of the synchronizer modules were placed near the klystron in the transmitter package. These modules consist of the FEL 130A synchronizer multipliers (A3, A12), tuner (A10), harmonic mixer (A11), and IF amplifier (A2) (Figure 5).

Coaxial cables are used for the 8-MHz and a 27.365-MHz signal links. A CAL-constructed line driver (U6), (Figure 6) provides a low-impedance 27.365-MHz signal output. A schematic of the line driver is given in Figure 11.

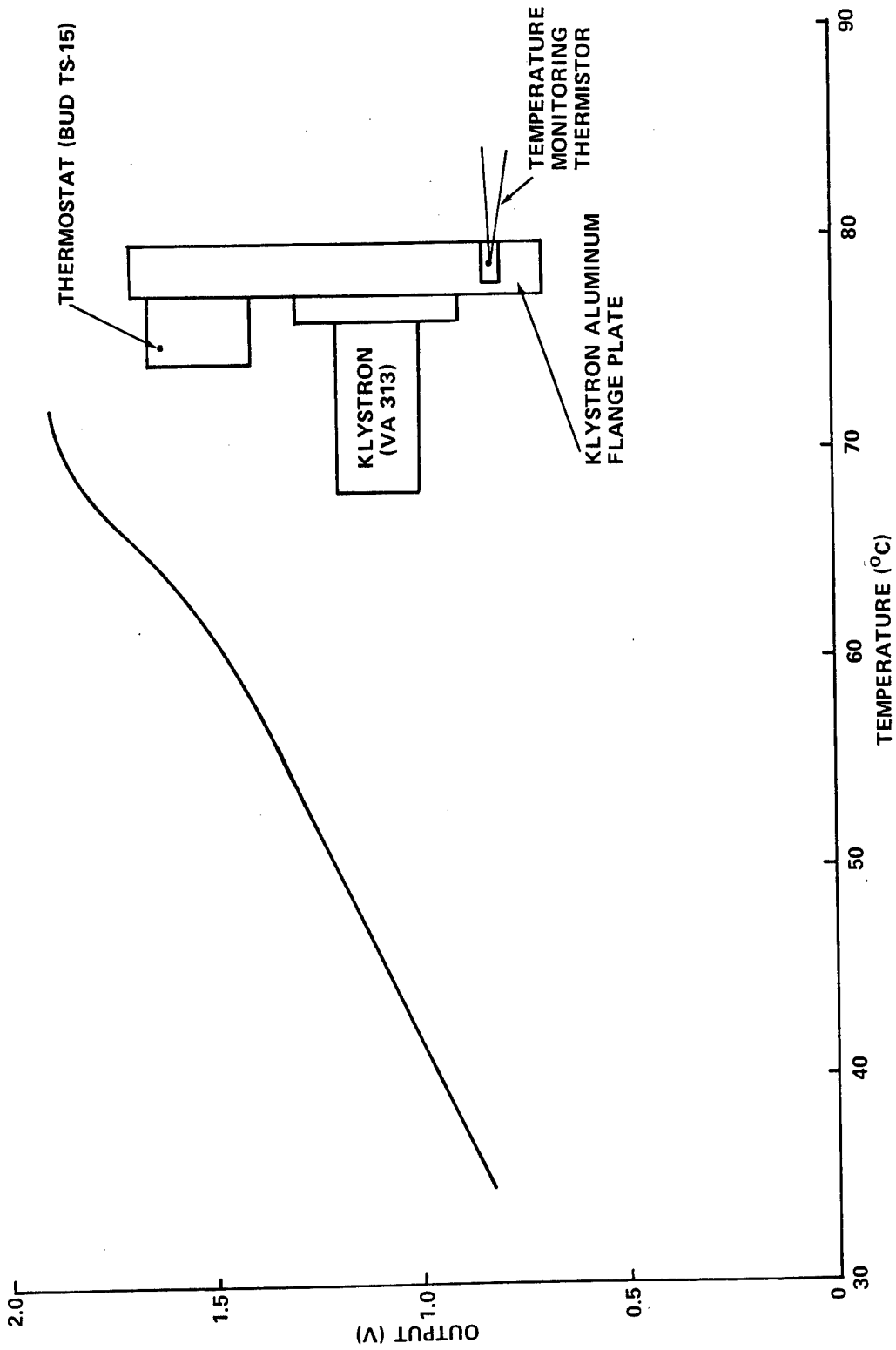


Figure 9 TEMPERATURE SAFETY CONTROL CIRCUIT OUTPUT VOLTAGE VERSUS
KLYSTRON FLANGE TEMPERATURE

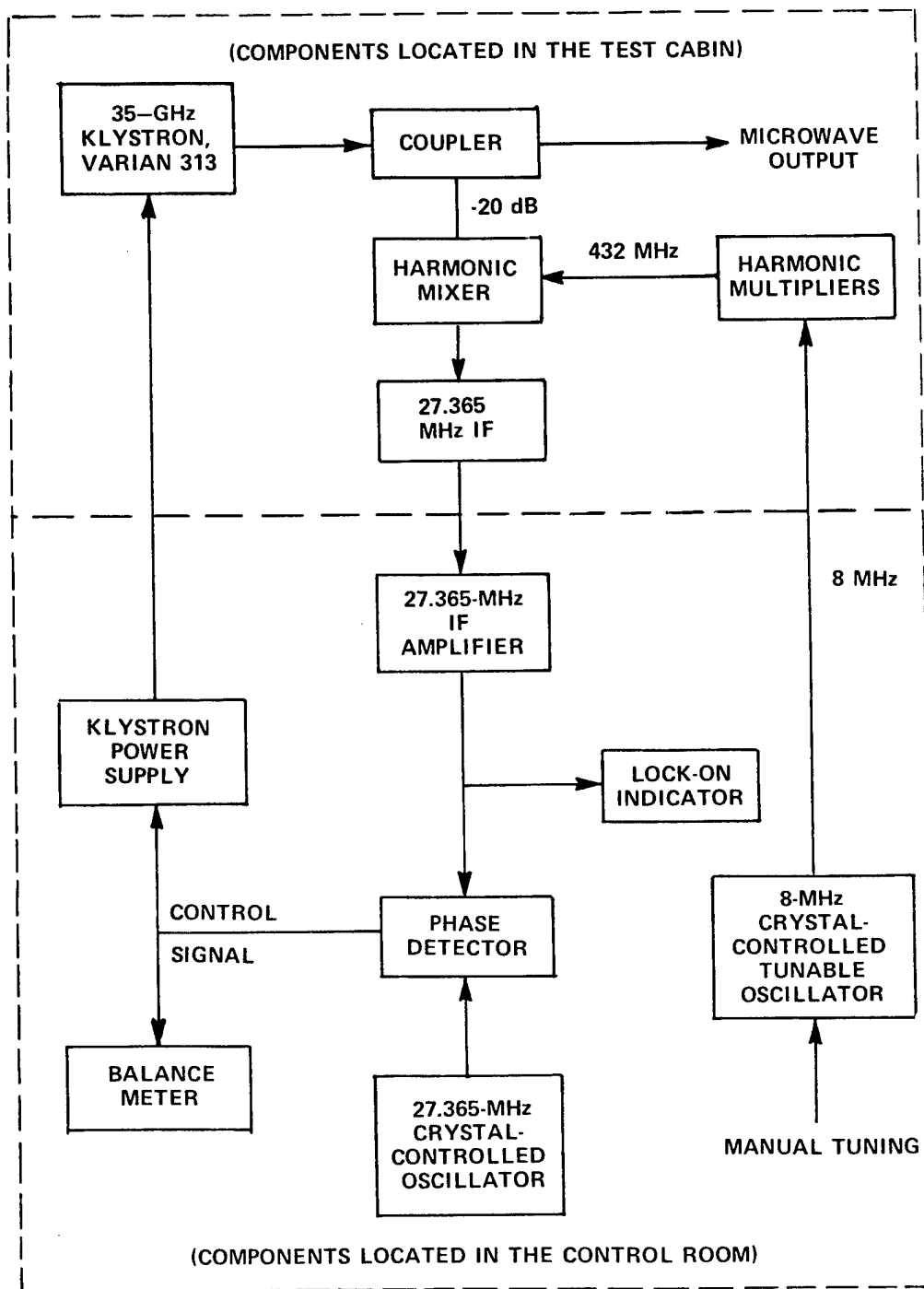


Figure 10 PHASE LOCK LOOP

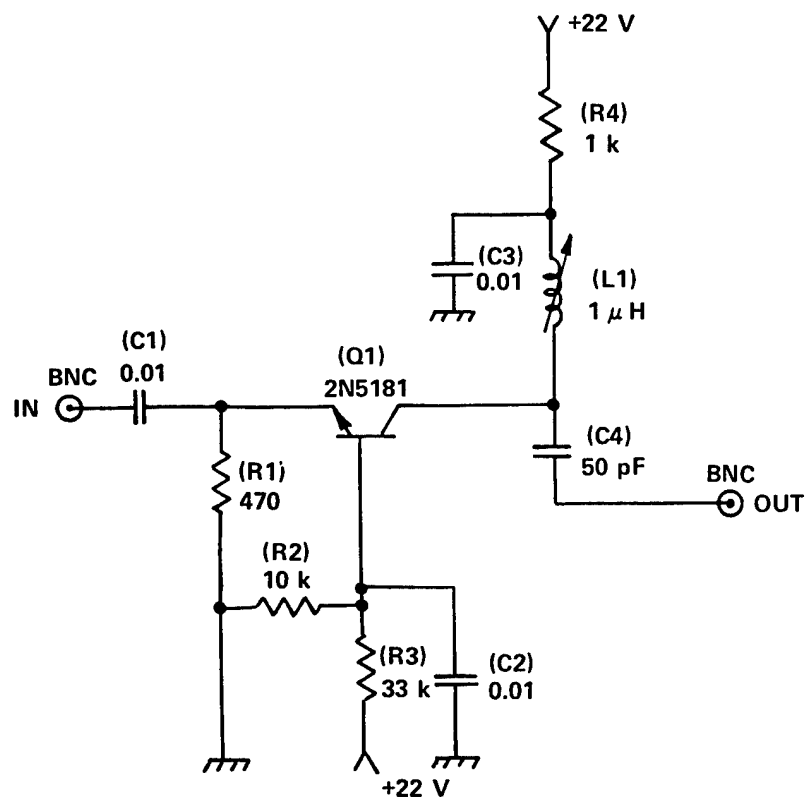


Figure 11 27-MHz LINE DRIVER

DC power for the operation of the phase lock modules in the transmitter package is supplied from the 22-VDC power supply in the FEL synchronizer unit. A block diagram showing the modifications and additions to the FEL synchronizer unit, including the temperature safety control circuit for protection of the klystron, is shown in Figure 12. The synchronizer chassis is mounted in the radar control rack shown in Figure 12.

2.5 KLYSTRON POWER SUPPLY

This unit consists of a Microdot Type FD-00-CV-BV power supply which is set to supply the following voltages through 150 feet of cable to the microwave klystron:

Filament Voltage	7.5 VDC (650 mA) *
Beam (Cathode) Voltage	-650 VDC (45 mA)
Reflector Voltage	-1020 VDC (0 mA)

A "trip" circuit internal to the power supply is remotely controlled by the temperature safety control circuit discussed earlier. The "trip" circuit shuts off all klystron power when activated. To restore power, the power supply must first be switched off and then on, because of a built-in interlocking circuit. For further details and schematic diagrams of this unit, the reader is referred to the manufacturers instruction manual (Reference 3).

2.6 MIXER-PREAMPLIFIER

The mixer-preamplifier consists of a balanced mixer, Microwave Development Laboratory MDL-28MH56-1, and a CAL-constructed preamplifier, which are packaged together as an integral unit. It is mounted directly on the receiver antenna waveguide output as shown in Figure 13. Local oscillator power is supplied to the mixer via a short length of flexible waveguide. The microwave mixer crystals are a forward and reverse pair, type IN53CMR microwave diodes. The signal output of the pre-amplifier is transmitted by coaxial cable to the main doppler amplifier in the radar signal processor unit.

* The filament voltage at the klystron is 6.3 VDC.

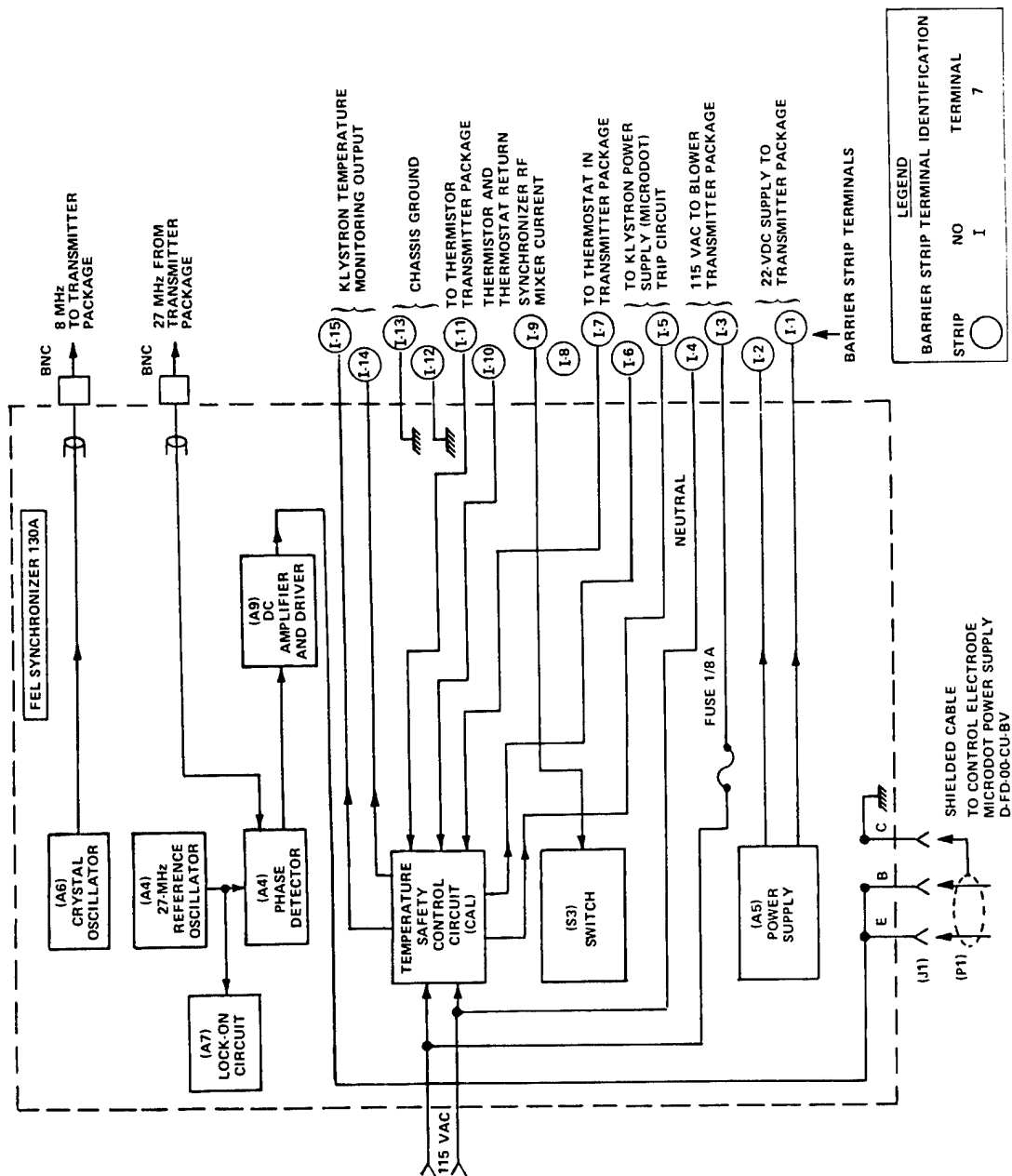


Figure 12 BLOCK DIAGRAM OF MODIFIED FEL 130A SYNCHRONIZER

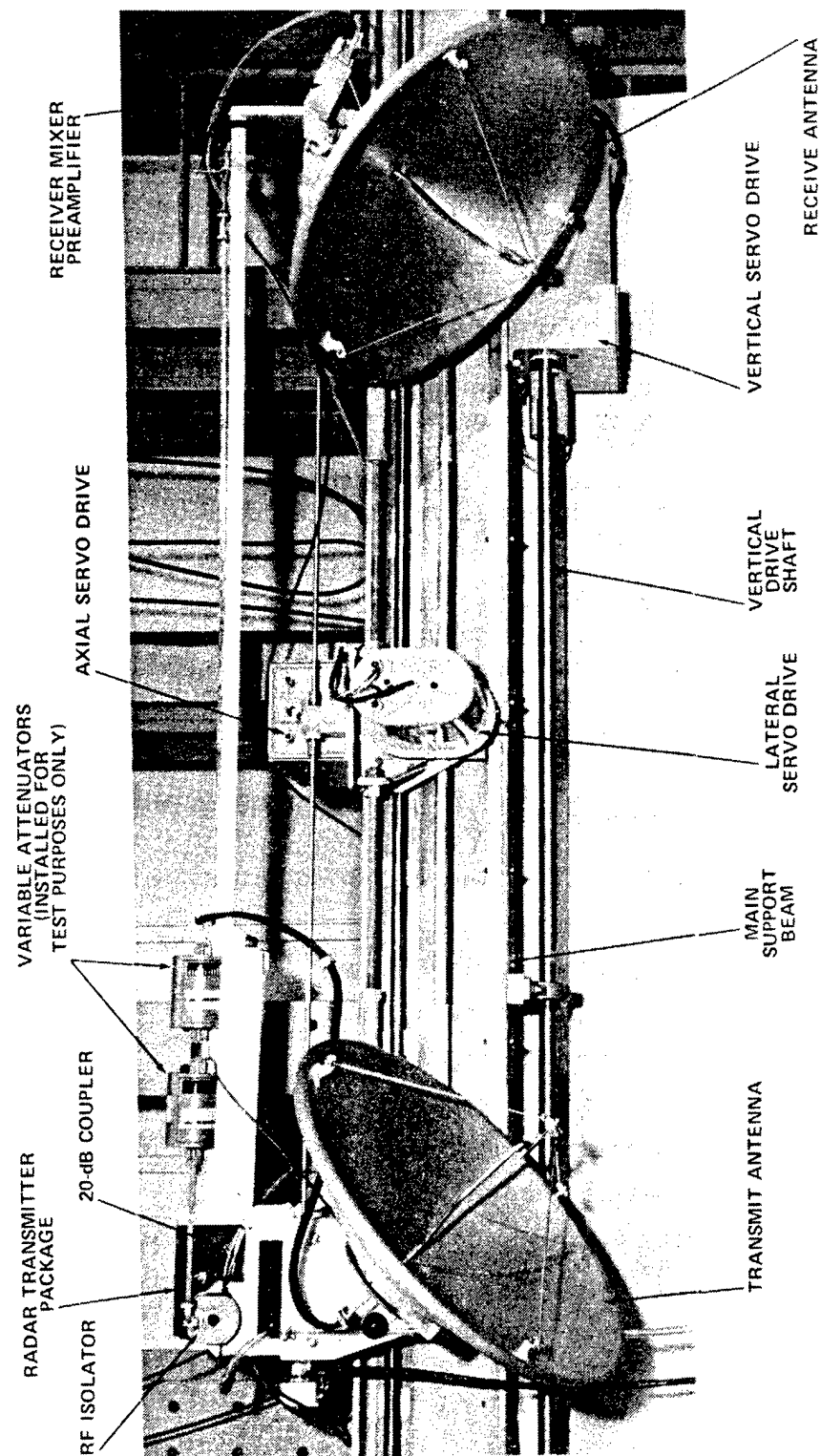


Figure 13 DETAIL OF RADAR ASSEMBLY WITH ANTENNAS

The schematic diagram of the mixer-preamplifier is shown in Figure 14. The output from the mixer at the junction of R1 and R2 is amplified by transistors Q1 and Q2. The preamplifier bandpass characteristic (Figure 15) is determined by the networks comprising R4 C3, R6 C4 and R5 C2. Transistor Q3 is a power amplifier which matches the output from the collector load of transistor Q2 to a 50-ohm coaxial output line. The local oscillator crystal current is measured as a voltage drop across resistors R1 and R2. This voltage is amplified in the differential, integrated circuit, amplifier A1. The output of the amplifier feeds the crystal current monitor on the radar signal processor chassis. The mixer local oscillator current is approximately 1 mA. The integrated circuit amplifier gain is adjusted to provide half-scale reading on the panel meter with this current. Shielded cables are used to bring the supply voltages from the control room to the mixer preamplifier. The DC leads into and out of the amplifier are filtered by the filters F1, F2 and F3.

The amplifier is designed to operate without external cooling in vacuum. Heat radiation and conduction through mounting flanges are sufficient to keep the operating temperature at a safe level. The amplifier is potted; the potting compound accelerates the heat transfer from inside components to the outside walls of the unit.

2.7 RADAR SIGNAL PROCESSOR

The processor contains the following subassemblies and components:

- (1) Main Doppler Amplifier
- (2) Frequency Meter (General Radio 1142-A)
- (3) Detector and Schmitt Trigger
- (4) Velocity Gating and Holding Circuit
- (5) Power Supplies (2) (Technipower M12.0 - 0.2)
- (6) Panel meters (2)
- (7) Velocity Calibration Potentiometer (Helipot Type A, 5000 ohm)

A block diagram is shown in Figure 16.

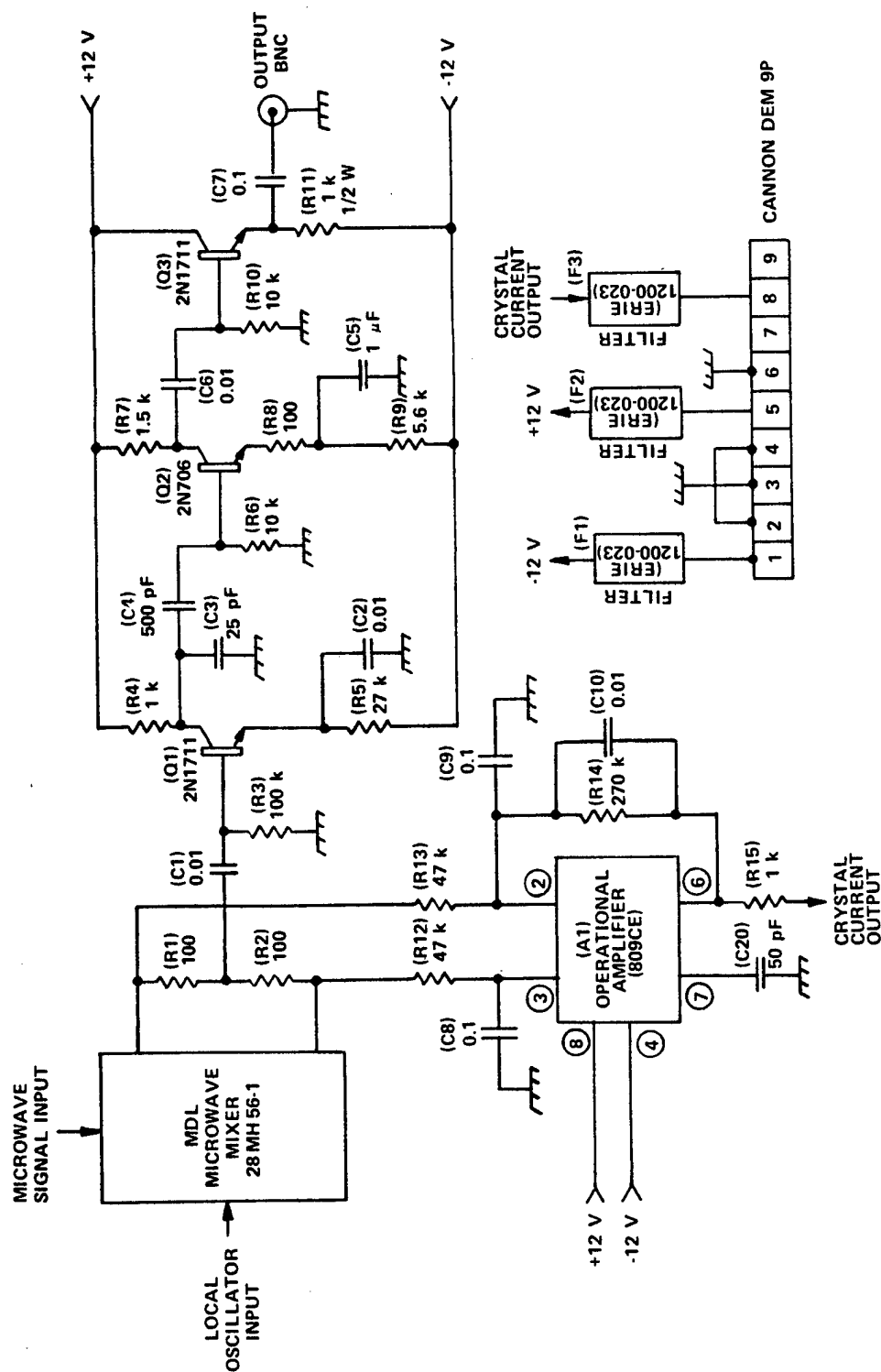


Figure 14 MICROWAVE MIXER AND PREAMPLIFIER

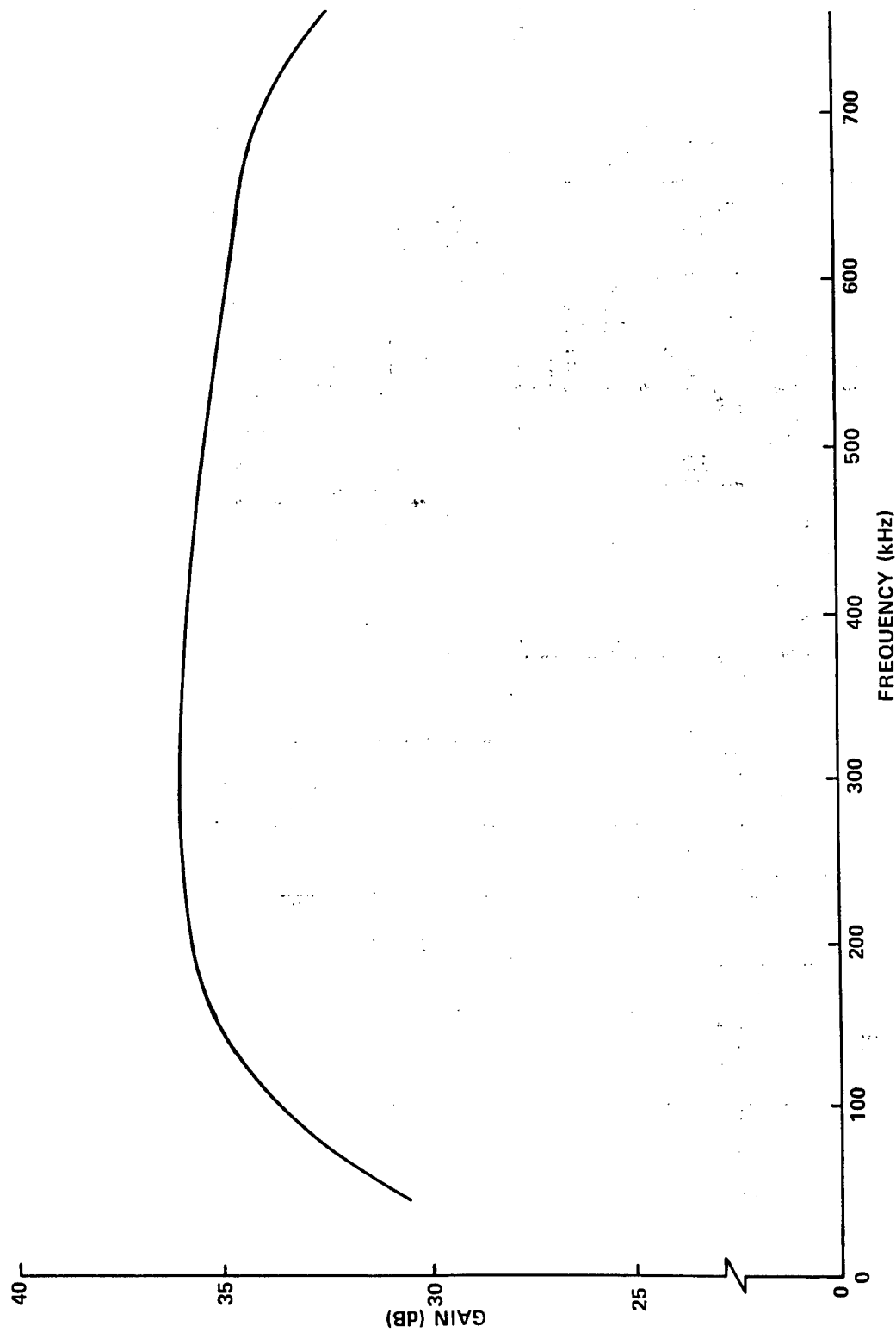


Figure 15 PREAMPLIFIER FREQUENCY RESPONSE

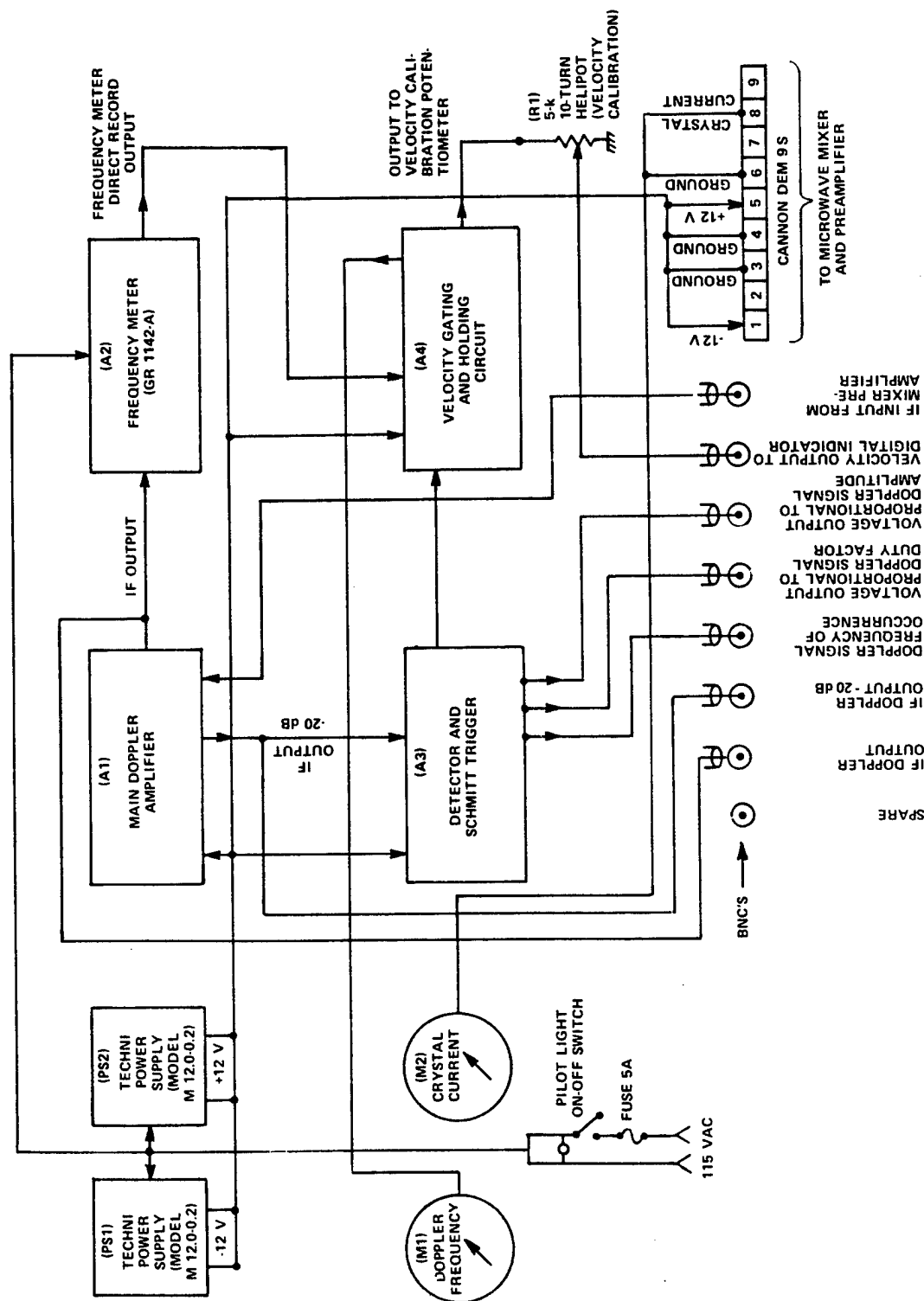


Figure 16 RADAR SIGNAL PROCESSOR BLOCK DIAGRAM

2.7.1 Main Doppler Amplifier

The main doppler amplifier provides additional gain for the doppler signal. A schematic diagram is shown in Figure 17. Three transistor pairs provide a maximum gain of approximately 60 dB. The bandpass characteristic is shown in Figure 18. The gain of the amplifier can be adjusted with potentiometer R5 in the collector of transistor Q2. The input at the base of Q1 is terminated with 56 ohm to match the characteristic impedance of the long coaxial line from the mixer-preamplifier. Two output levels are available at the amplifier. The maximum gain is at the output of the collector of transistor Q6. This output is fed via the transistor follower Q8 to the input terminals of the General Radio frequency meter. The output at the collector of Q4 is approximately 20 dB lower in level. This signal is fed via transistor follower Q7 to the Detector and Schmitt Trigger circuit.

It is noted that the low level output of the amplifier is used for the Detector and Schmitt Trigger circuit, providing a large dynamic range for measuring doppler signal amplitude. Saturation effects which may occur in the following stage of amplification do not affect system performance. This stage saturates by symmetrical clipping of the waveform which does not affect the operation of the General Radio frequency meter.

2.7.2 Frequency Meter

The frequency meter, General Radio Type 1142-A, measures the doppler frequency of the radar signal. The output of the main doppler amplifier is connected to the input terminals of the frequency meter. The output from the frequency meter is taken from the Direct Record terminals of the instrument. The output consists of constant voltage, constant width pulses. The number of pulses, and thus the average value of the output, is proportional to the frequency of the input signal. The frequency meter output is processed in the velocity gating and holding circuit described in subsection 2.7.4. The instruction manual for this instrument is supplied with the installation (Reference 4) and a detailed description of the operation of the frequency meter is given there.

2.7.3 Detector and Schmitt Trigger

The Detector and Schmitt Trigger circuit provides a threshold below which doppler signal inputs are not used in measurement of doppler velocity. If the doppler signal amplitude is below the threshold

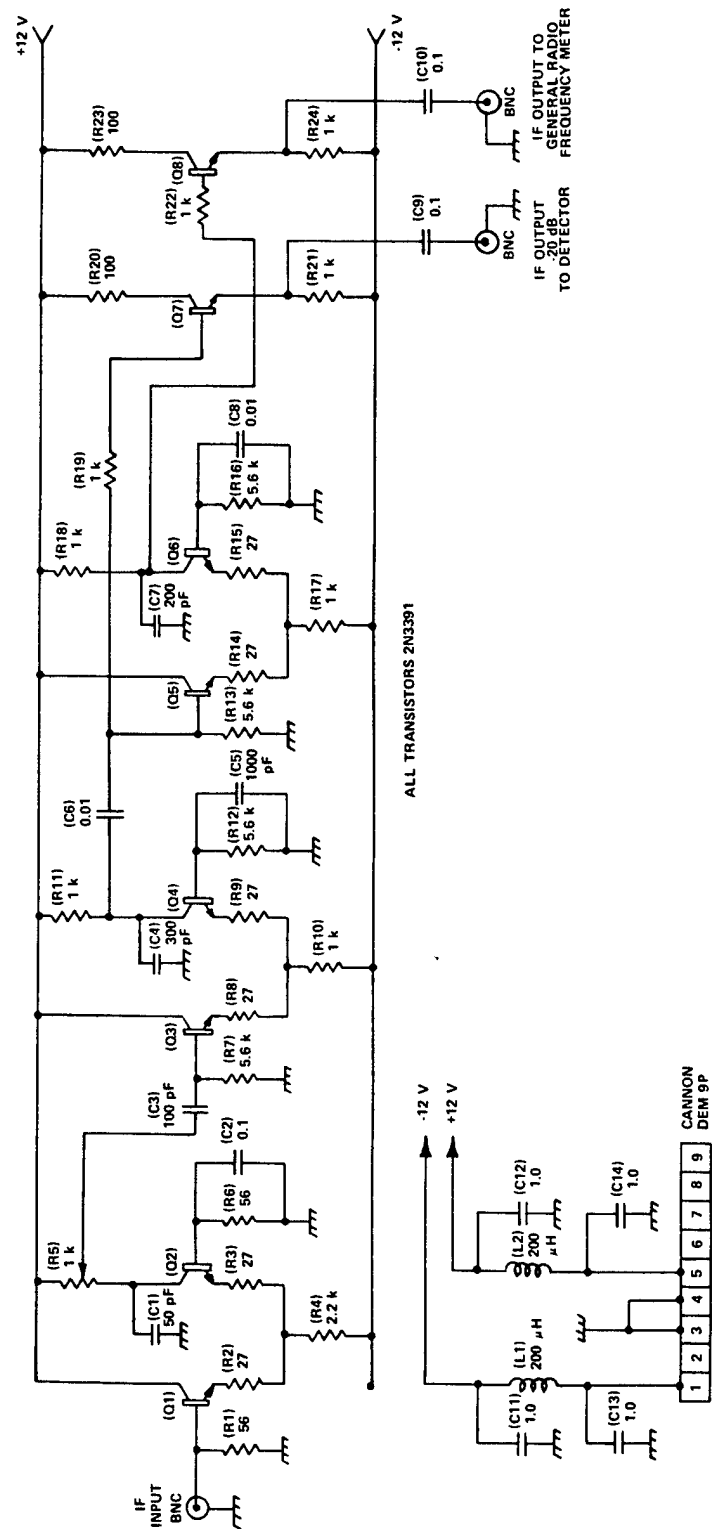


Figure 17 MAIN DOPPLER AMPLIFIER

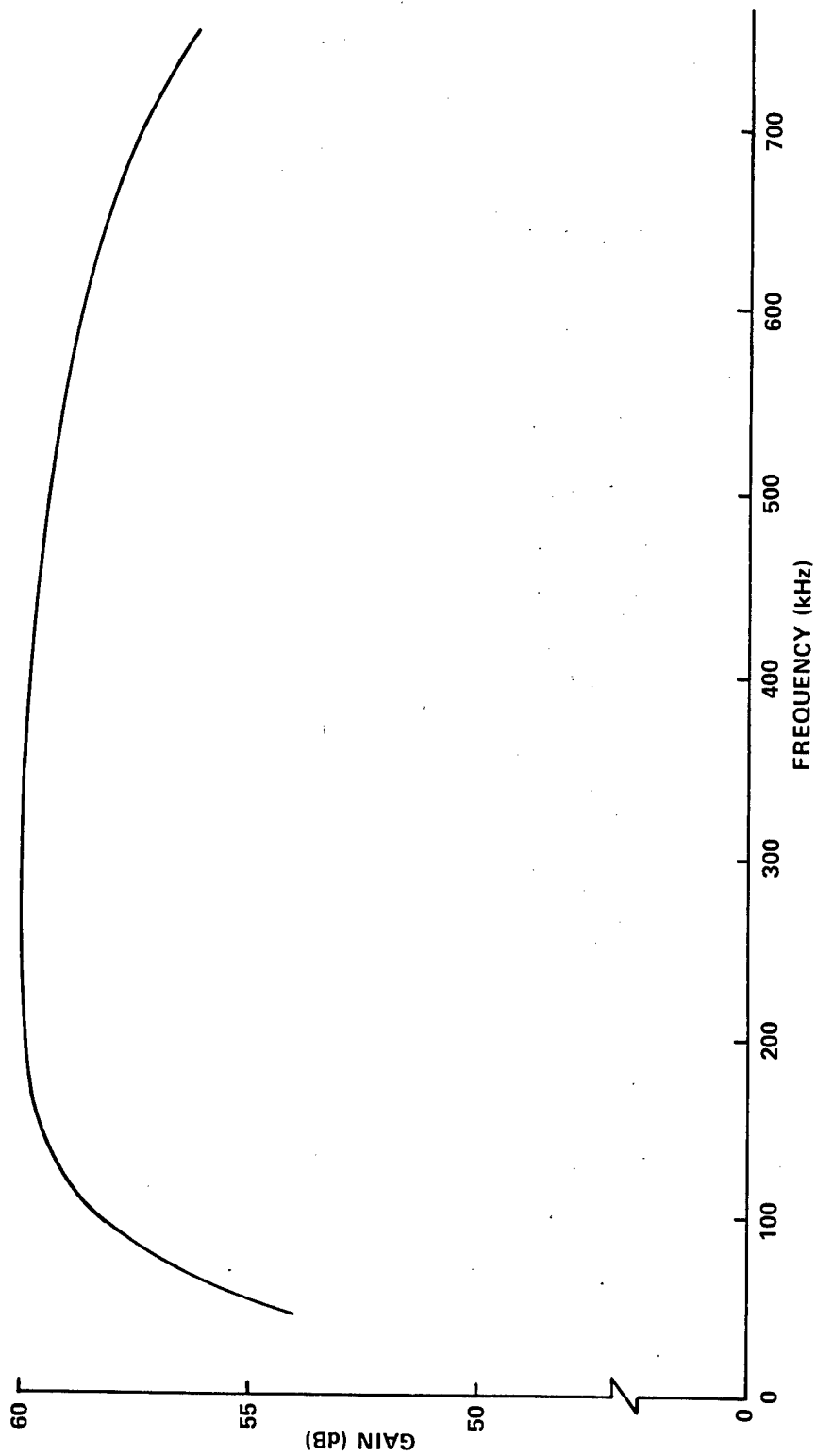


Figure 18 MAIN DOPPLER AMPLIFIER FREQUENCY RESPONSE

setting, the last valid velocity information is stored and read-out until the doppler signal amplitude again exceeds the threshold. A schematic diagram of the unit is shown in Figure 19.

The input doppler signal is peak detected by transistor Q1, and then smoothed by a lowpass filter consisting of R4, C2, L1 and C3. The filter, with a cutoff frequency of 45 kHz responds to input amplitude pulse "widths" exceeding approximately 5 μ s. The output of the lowpass filter is fed to an integrated circuit operational amplifier A1, which is used as a voltage follower. The output of amplifier A1 is applied to the Schmitt trigger A2 via resistor R7. The Schmitt trigger is biased off by a threshold voltage, set by potentiometer R18, which is applied to the Schmitt trigger via transistor Q2 and resistor R8. Whenever the voltage at the output of amplifier A1 exceeds the threshold voltage setting produced by potentiometer R18, the Schmitt trigger changes state and the output voltage at terminal 7 of Schmitt trigger A2 switches from 0 volt to approximately +5 volts. This output voltage is fed to the Velocity Gating and Holding Circuit where it is used to gate the output signal of the General Radio frequency meter. The Schmitt trigger output is made available at the emitter of transistor follower Q3. Frequency of Occurrence or the rate at which the doppler signal exceeds the threshold level can be monitored at this point. The output of Schmitt trigger A2 is in addition applied to the operational amplifier A3 via a smoothing network consisting of resistor R10 and capacitor C6. The time constant of this network, including the parallel input impedance of the amplifier, is about 0.01 second. The smoothed output at terminal 6 of amplifier A3 is proportional to the mean duty factor (defined here as the percentage of time the doppler signal exceeds the threshold level. The gain of amplifier A3 is adjustable by potentiometer R11.

A BNC output jack is available for monitoring the average doppler signal amplitude. This output is obtained from amplifier A4, which amplified the output signal from amplifier A1. The averaging of the detected signal is accomplished by the RC network consisting of R13, R14, and C8. The time constant of this network is approximately 0.01 second.

The outputs of amplifiers A3 and A4 are made available at BNC output jacks for purposes of monitoring and recording. Resistors are placed in series with these outputs as shown in the schematic to protect the operational amplifiers against accidental shorting of their output terminals.

2.7.4 Velocity Gating and Holding Circuit

The General Radio frequency meter output is gated in this circuit by the MOS FET gate Q1 shown in the schematic diagram of Figure 20. The output of the frequency meter is applied to the operational amplifier A1 via a lowpass filter network consisting of C1, L1, and C2. Amplifier A1 is used as a voltage follower. The filter network smoothes the output of the frequency meter with an equivalent time constant of approximately $5 \mu s$. When the doppler signal exceeds the threshold setting, the Schmitt trigger is fired, the emitter of Q2 is above ground, transistor Q3 conducts, and the MOS FET gate Q1 conducts. Capacitor C5 is charged quickly via resistor R4 to the doppler velocity voltage supplied by amplifier A1. This voltage is passed via the high impedance input FET operational amplifier A2 to amplifier A3, both of which are used as voltage followers.

When the doppler signal level falls below the threshold level, the Schmitt trigger switches to its offstate and transistors Q2, Q3 and the MOS FET gate Q1 are cut off. Capacitor C5 remains charged with the last input level received from amplifier A1 and this level is read out by amplifier A3 as before. Whenever the doppler signal exceeds the threshold level, the velocity information stored in capacitor C5 is updated.

The output of amplifier A3 is fed to a panel meter on the Radar Signal Processor chassis and to a 5000-ohm 10-turn Helipot type A, potentiometer, shown in Figure 16. The panel meter indicates doppler frequency; potentiometer R11 (Figure 19) is used to calibrate the meter. Full-scale corresponds to a doppler frequency of 500 kHz. The Helipot potentiometer feeds a digital indicator located on the antenna position control panel. The indicator reads the measured velocity directly when the Helipot potentiometer is correctly adjusted (subsection 4.4.2) and calibrated for the particular antenna test configuration in the test cabin. The digital read-out is in kilofeet per second, showing the three significant numbers.

2.8 WIRING DIAGRAM

Figure 21 shows the wiring and interconnections between the radar units. Shielded polyethylene wiring is used for all power connections; coaxial cable is used for the signal leads between the tunnel test section and the control room.

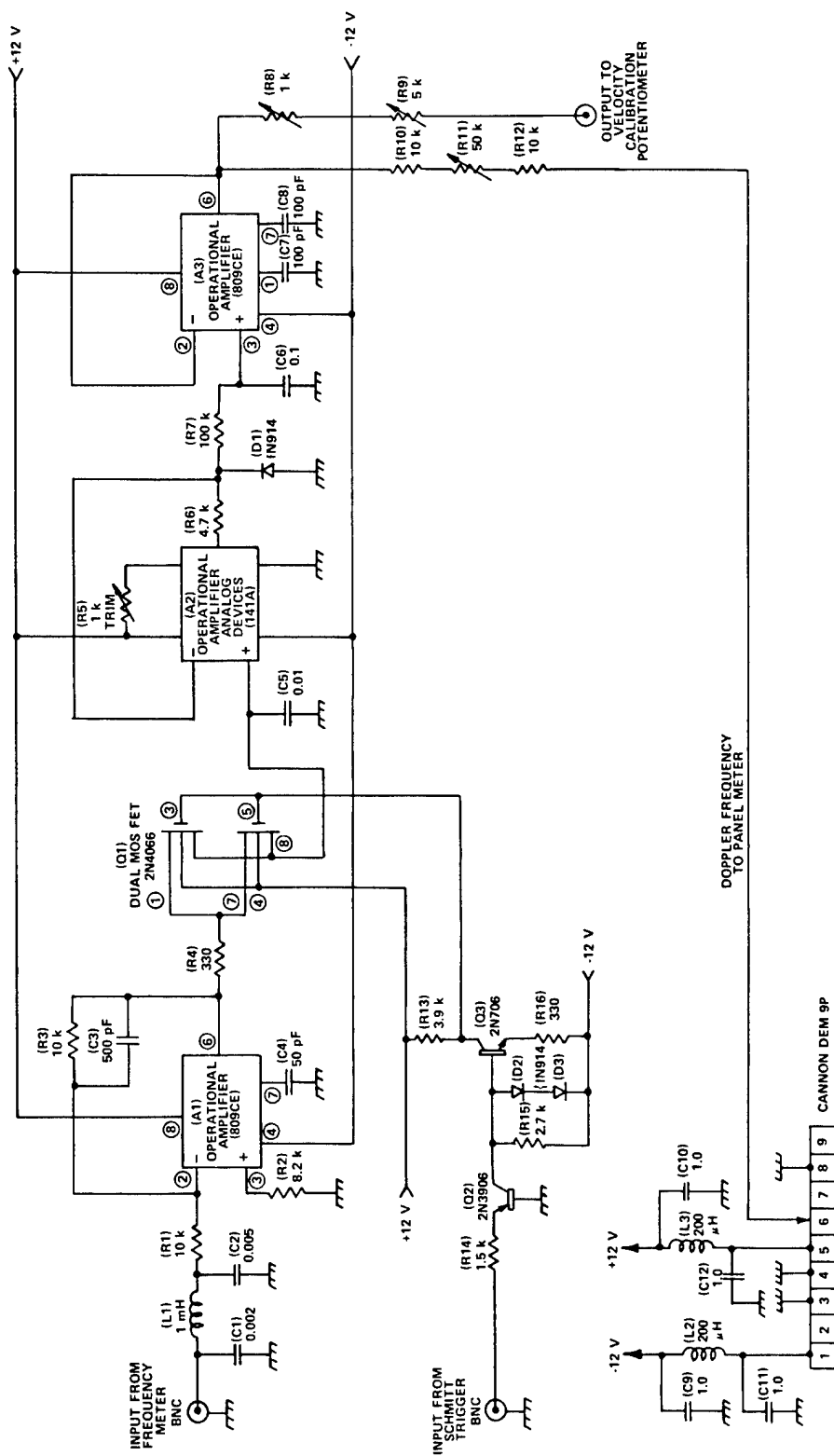


Figure 20 VELOCITY GATING AND HOLDING CIRCUITS

Section III

RADAR OPERATING INSTRUCTIONS

Before placing the radar system in operation, check the wiring between units and ascertain that all power and signal connectors are properly aligned and secured. Care must be exercised in engaging and disengaging the high-voltage connectors on the transmitter package. Damage to the rubber compound enclosing the pins and sockets will make the connectors susceptible to arcing and corona in the vacuum environment and render the system inoperable. The test cabin should be checked and cleared of all obstacles which may interfere with operation of the antenna positioning system.

The radar system is operated from three radar control panels (i.e., synchronizer, radar signal processor and klystron power supply) shown in Figure 22. Each of these units is supplied with its own 115-VAC power cord.

The synchronizer is in a standby condition when it is connected to the 115-volt power. In standby, the crystal reference oscillator oven is energized and the oven indicator glows. It is recommended that the synchronizer be left in standby to maintain oscillator stability and eliminate oven warmup.

3.1 TRANSMITTER SWITCH-ON

To switch on the klystron transmitter, power must first be switched on to the synchronizer FEL 130A, and then to the klystron power supply Microdot D-FD-00-CU-BV. To monitor microwave output power, the radar signal processor must also be switched on. The "STD BY" pilot light on the klystron power supply indicates that power is supplied to the klystron filament, but no high voltages are supplied to the beam or the reflector. After a period of approximately 60 seconds, the high-voltage circuits are automatically energized. The "ON" pilot light on the klystron power supply goes on, indicating that all voltages are supplied to the klystron tube.

Note that the klystron power supply voltages have been adjusted for proper operation of the klystron. The voltage adjustment controls on the front panel of the klystron power supply have been locked and should not be changed. (The high-voltage outputs must be checked, however, without the transmitter connected; if for any reason the voltage control settings are to be readjusted, see subsection 2.5).

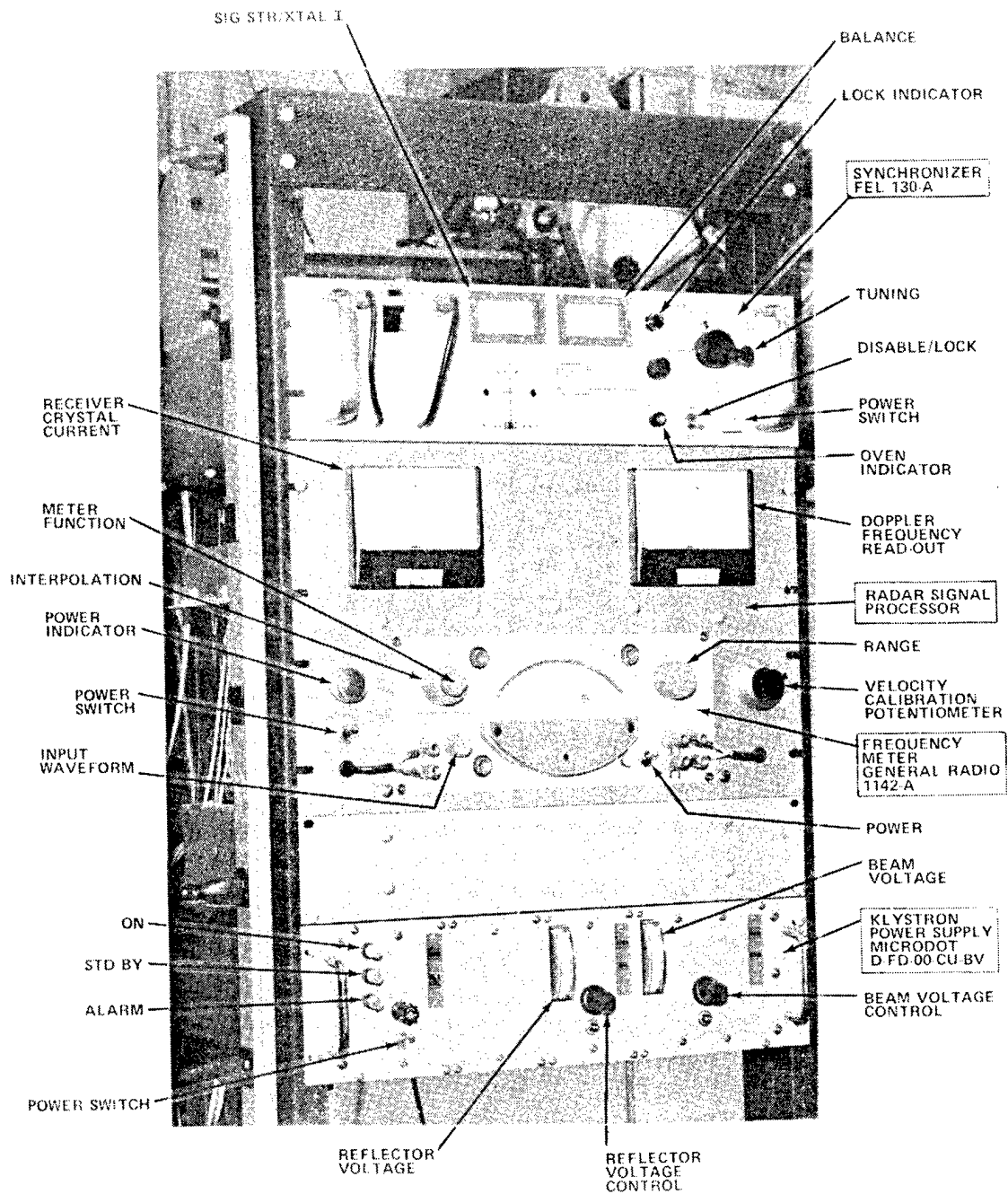


Figure 22 RADAR CONTROL PANELS

The microwave power is monitored by the receiver crystal current meter on the radar signal processor panel. This meter reads approximately mid-scale when the radar mixer-preamplifier is properly connected. The klystron output power for this meter reading is 200 mW and the transmitted power is approximately 100 mW.

The "ALARM" indicator light on the klystron power supply goes on when the internal trip circuit of the supply is activated. This action switches off all klystron power. When the cause for the alarm has been cleared, klystron power can be reapplied by first turning the supply power switch to off and then to on.

3.2 TRANSMITTER LOCK-ON

After the klystron has been turned on, allow 20 minutes for the klystron to stabilize. No attempt should be made before that time to phase lock the klystron. The operating procedure for phase locking is as follows: turn the "DISABLE/LOCK" switch on the synchronizer FEL 130A panel to the up position and the "SIG STR/XTAL I" switch to the "SIG STR" position. Rotate the tuning knob until a number is centered in the window and slowly continue the rotation until a signal is indicated on the "SIG STR/XTAL I" meter. When no signal is observed, advance the tuning knob to the next position number in the window and continue the rotation. There are 10 window positions which are successively searched by continuous rotation of the tuning knob. Usually, several signals are observed on the "SIG STR/XTAL I" meter for different window and tuning knob positions. The optimum signal will have a signal strength reading of 7 or higher on the meter with the crank handle of the tuning knob in the down position. This position of the tuning knob allows maximum tuning variation, since it is the center of the crystal oscillator tuning range. Next, switch the "DISABLE/LOCK" switch to lock at which position the "LOCK" indicator should light indicating phase lock. If the "LOCK" indicator does not light, rotate the tuning knob slowly back and forth until lock is obtained. Then rotate the tuning knob for balance as indicated on the balance meter. Occasionally a strong signal is indicated by the "SIG STR" meter for which lock cannot be obtained. Such a signal should be disregarded and another selected for the lock operation.

3.3 RADAR SIGNAL PROCESSOR SWITCH-ON

When the power switch is turned on, the power indicator light goes on and power is applied to all radar receiver circuits. The frequency meter General Radio 1142-A controls must be set as follows:

Power	On
Range (Frequency)	1.5 MHz
Meter Function	Direct
Interpolation Switch	1.0
Input Waveform	Sine Wave

This completes the turn-on procedure for the transmitter and receiver portions of the radar. Refer to Section 7 for the turn-on procedure for the antenna positioning servo system.

For turn-off, the above procedure is reversed.

Section IV

ALIGNMENT, CALIBRATION, AND CHECKOUT OF THE RADAR SYSTEM

The radar installation is an experimental system which has not been tested under operational conditions in the AFFDL 50-Megawatt Electrogasdynamics Facility. The alignment and calibration procedures described therefore are preliminary and are provided as guidelines for initial preparation of the radar instrument before commencing tests.

4.1 ANTENNA ALIGNMENT

The two focal points of the elliptical antenna are $f_1 = 9.60$ inches and $f_2 = 45.60$ inches. The point where the collimated beam converges (i.e., at f_2 when the antenna is fed from f_1) can be varied between 40 and 61 inches by changing feed position.

A typical geometrical configuration for the transmitting and receiving antennas is shown in Figure 23. The beams converge at points 51.5 inches from the centers of the reflectors. The radar resolution cell is the small common volume of the beams at the intersection point.

A special tool, supplied with the radar and shown in Figure 24, facilitates the antenna alignment. An alignment tool is attached to each antenna and the antennas are adjusted until their respective focal points coincide. The antenna pointing angles can be adjusted by means of work positioners which are discussed in subsection 5.1.4.

Fine adjustments of antenna pointing directions can be made by using a modulated diode placed at the nominal common focal point and adjusting antenna pointing directions for maximum radar signal strength. The diode (Figure 25) is used to modulate the backscattered microwave signal. The modulated signal is detected, amplified and displayed on an oscilloscope. Because of the high received signal level, the oscilloscope can be connected directly to the radar receiver mixer-preamplifier, allowing this adjustment to be performed in the tunnel test cabin. It is recommended that the diode be mounted on a thin (1/8-inch-diameter) wood dowel, approximately 1 foot in length, and that connections be made to the diode with #30 or smaller diameter wire. The antenna should be positioned carefully until maximum signal output is observed on the oscilloscope. For a discussion of the effect of the phase of the microwave signal on the observed signal amplitude which is also important here, the reader is referred to subsection 2.5.1 of the technical report (Reference 5).

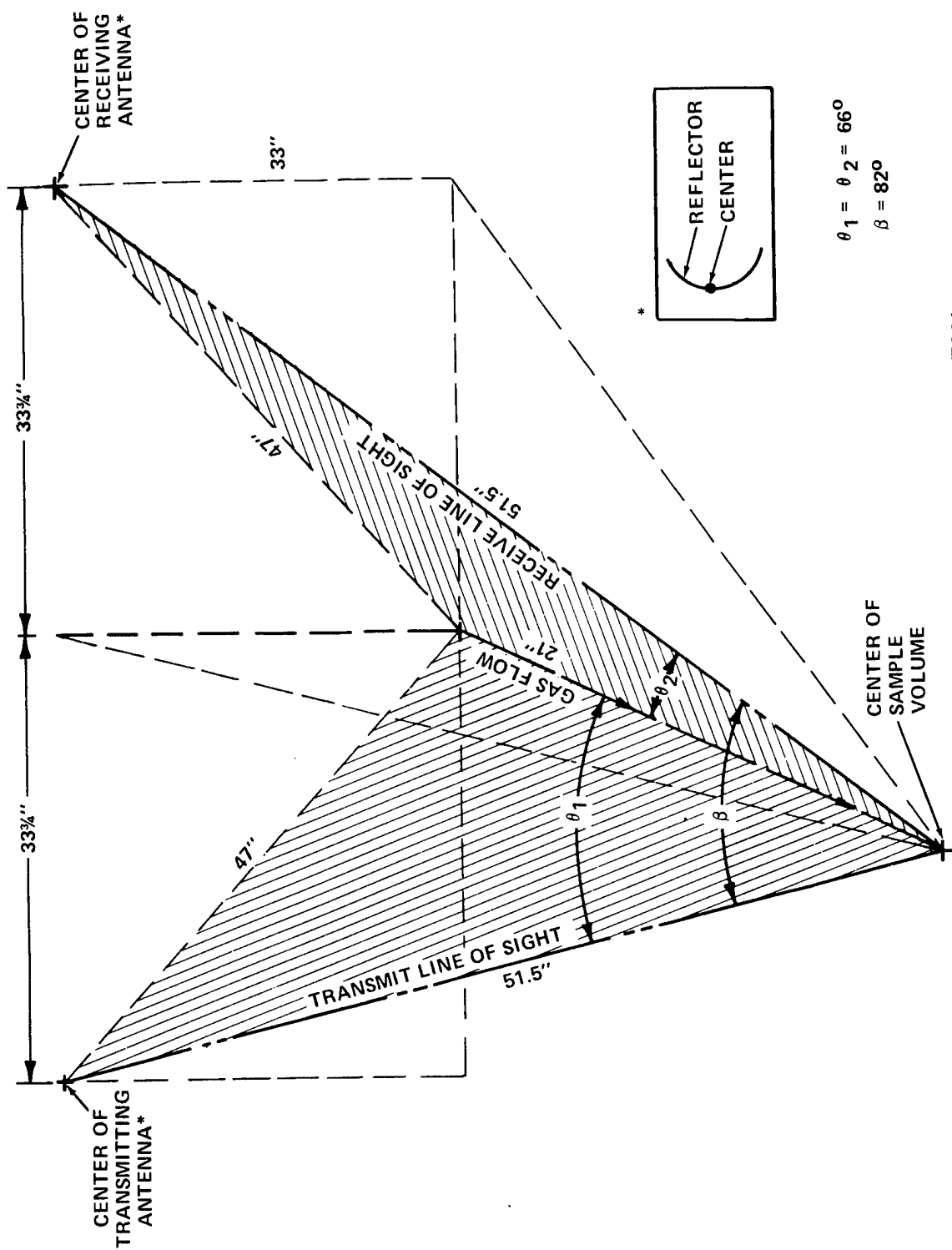


Figure 23 BISTATIC ANTENNA GEOMETRY

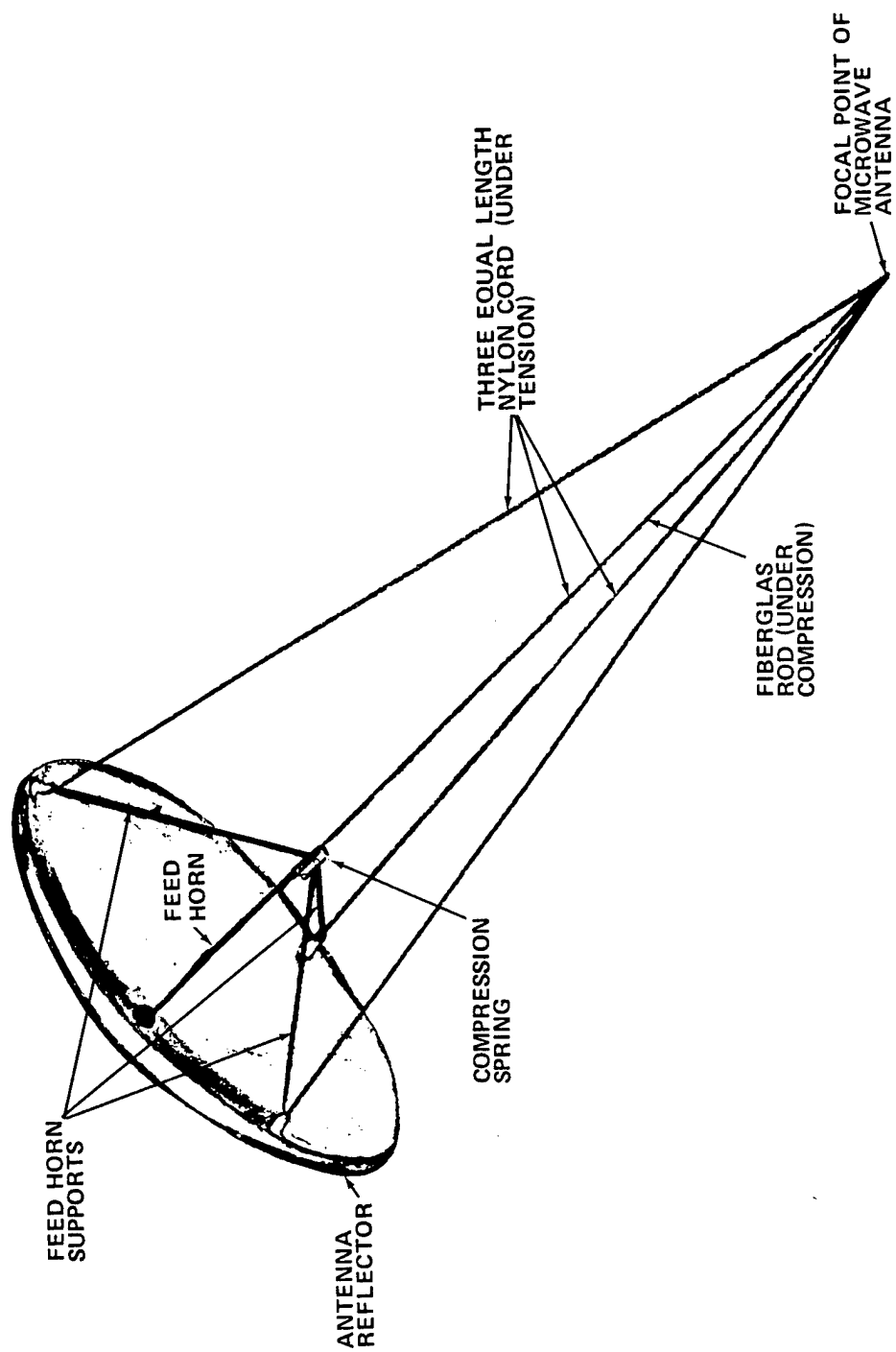


Figure 24 ANTENNA ALIGNMENT TOOL

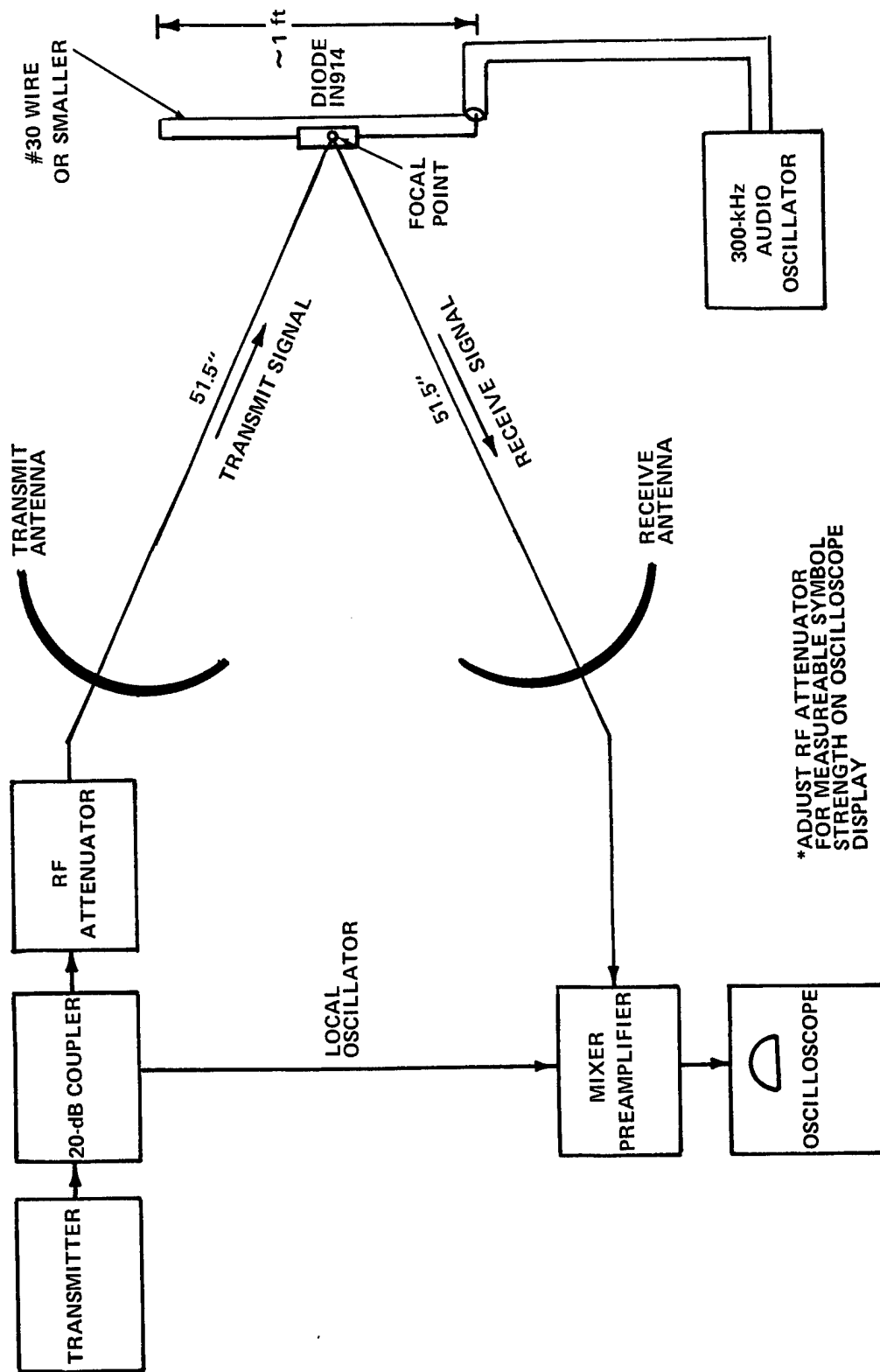


Figure 25 ANTENNA ALIGNMENT TECHNIQUE

After the antennas are aligned, the intersection angles between each radar beam axis and a line parallel to the gas flow (tunnel center-line) should be determined. These angles, θ_1 , and θ_2 as shown in Figure 23, are required in calculating the velocity from the doppler data.

4.2 MICROWAVE FREQUENCY AND POWER TESTS

The klystron is mechanically tuned to 35.0 GHz. Its mechanical tuning range is 700 MHz and electronic tuning range approximately 60 MHz. The power output is approximately 200 mW. The output power and frequency must be periodically checked with a power meter (Hewlett Packard Type 431B) and frequency meter (FXR Type U410A). The local oscillator port can be used for this measurement (Figure 3). The microwave power at this port must be in excess of 1 mW.

4.3 SIGNAL PROCESSOR THRESHOLD ADJUSTMENT

The threshold setting for the Schmitt trigger A2 (Figure 19) is adjusted to operate at a signal level 10 dB above the receiver noise level. With the radar system in operation, the noise input level to the Detector and Schmitt Trigger circuit is approximately 30 mV RMS. With this level, the Schmitt trigger should only occasionally be activated. The threshold setting can be checked by applying a 100-mV RMS 300-kHz signal to the input of the Detector and Schmitt trigger circuit (Figure 19). At this input level, the Schmitt trigger output must just switch to the high state. The switching threshold can be adjusted by means of potentiometer R18. The Schmitt trigger is in its low state when the output to the Velocity Gating and Holding circuit is less than +0.5 volt; the high state is indicated by a voltage level in excess of +5 volts.

4.4 RADAR OUTPUT CALIBRATIONS

4.4.1 Doppler Frequency Meter

Apply a 10-mV, 300-kHz (+1%) sinusoidal signal to the input of the Main Doppler amplifier (Figure 16) and adjust potentiometer R11 of the Velocity Gating and Holding circuit (Figure 20) until the doppler frequency meter M1 (Figure 16) reads 30 on the meter scale. Meter readings are converted to doppler frequency readings by applying a multiplication factor of 10,000.

4.4.2 Digital Velocity Read Out

Calculate the doppler frequency for a velocity of 10,000 ft/s from

$$fd = \frac{2v}{\lambda} [\cos \theta_1 + \cos \theta_2]$$

where

$$v = 10,000 \text{ ft/s}$$

$$\lambda = 0.0281 \text{ ft}$$

θ = angle between line of sight of transmitting antenna and the direction of flow (Figure 23).

θ = angle between line of sight of receiving antenna and the direction of flow (Figure 23).

Apply a 10-mV signal at the computed frequency fd (+0.1%) to the input of the Main Doppler Amplifier (Figure 16), and adjust potentiometer R1 (Figure 16) until the digital velocity indicator on the antenna position control panel reads 10.0. The velocity indicator is then calibrated in kft/s for the actual test configuration.

4.4.3 Doppler Signal Frequency of Occurrence

To measure the frequency of occurrence, an event counter can be connected to this output. The output consists of a positive voltage step from 0 to approximately +5 volts.

4.4.4 Doppler Signal Duty Factor

The duty factor is 100 percent when the output of the Schmitt trigger (Figure 19) is high. The output voltage is linear between 0 volts and its 100 percent value with duty factor variations.

4.4.5 Doppler Signal Time History and Signal Amplitude

The doppler (IF) signal is available for direct recording purposes at the IF doppler output connector of the Radar Signal Processor (Figure 16). The relative signal level is calibrated at the

"Signal Amplitude" output connector (Figure 16) by applying a 300-kHz signal to the Main Doppler Amplifier input and plotting the DC level at the "Signal Amplitude" output connector as a function of the 300-kHz input level.

4.5 SUMMARY OF RADAR OUTPUTS

The bandwidth, impedance and voltage ranges of the radar inputs are:

Radar Output	Nominal Output Level (V)	Nominal Impedance Level ($k\Omega$)	Maximum Frequency Response (Hz)
Mean Velocity	+0.5 to +1.0	1	100
Doppler Signal Frequency of Occurrence	0 to +5.0	0.2	100 k
Doppler Signal Duty Factor	0 to +2.0	3	100
Doppler (IF) Signal	0 to +2.0	1	700 k
Doppler Signal Amplitude	0 to +2.0	3	100

Section V

ANTENNA POSITIONING SYSTEM

The antenna positioning system consists of a three-axis electro-mechanical positioning mechanism located in the tunnel test cabin and the servo control panel in the arc heater control room. The antenna positioning system is shown in Figures 26 through 28. An itemized listing of CAL drawings, related subassemblies, and components is given in Appendix II. The servo control panel shown in Figure 22 permits operation of the antenna positioning system from the control room. A series of wiring diagrams appearing in Figures 29 through 32 show both the control panel wiring and the wiring of the positioning mechanism within the tunnel.

5.1 SERVO POSITIONING MECHANISM

The servo positioning mechanism illustrated in Figures 26 through 28 permits mechanical positioning of the antenna along three mutually perpendicular directions. These directions are determined by a system of guide rods as follows.

Vertical travel:	Item No. 44	Figure 26
Lateral travel:	Item No. 21	Figure 26
Axial travel:	Item No. 13	Figure 27

These rods support and guide those members which are being moved in a particular direction of travel. Minimum load is carried by the axial axis guide rods, since only the antenna, transmitter and associated microwave components are moved in the axial (parallel to the stream) direction. The lateral axis, however, carries all items moved by the axial axis plus the antenna carriage weldments (Item 11, Figure 28) and the central carriage subassembly (Item 8, Figure 26). Finally, the vertical axis moves the entire beam assembly, carrying with it all servo components.

The movement along each axis is provided by a DC motor servo system utilizing mechanical ball screw jacks to convert the rotational motion into the linear motion required. High-accuracy lead screw, screw jack mechanisms are used to minimize backlash effects which are inherent with many of the standard screw-nut combinations.

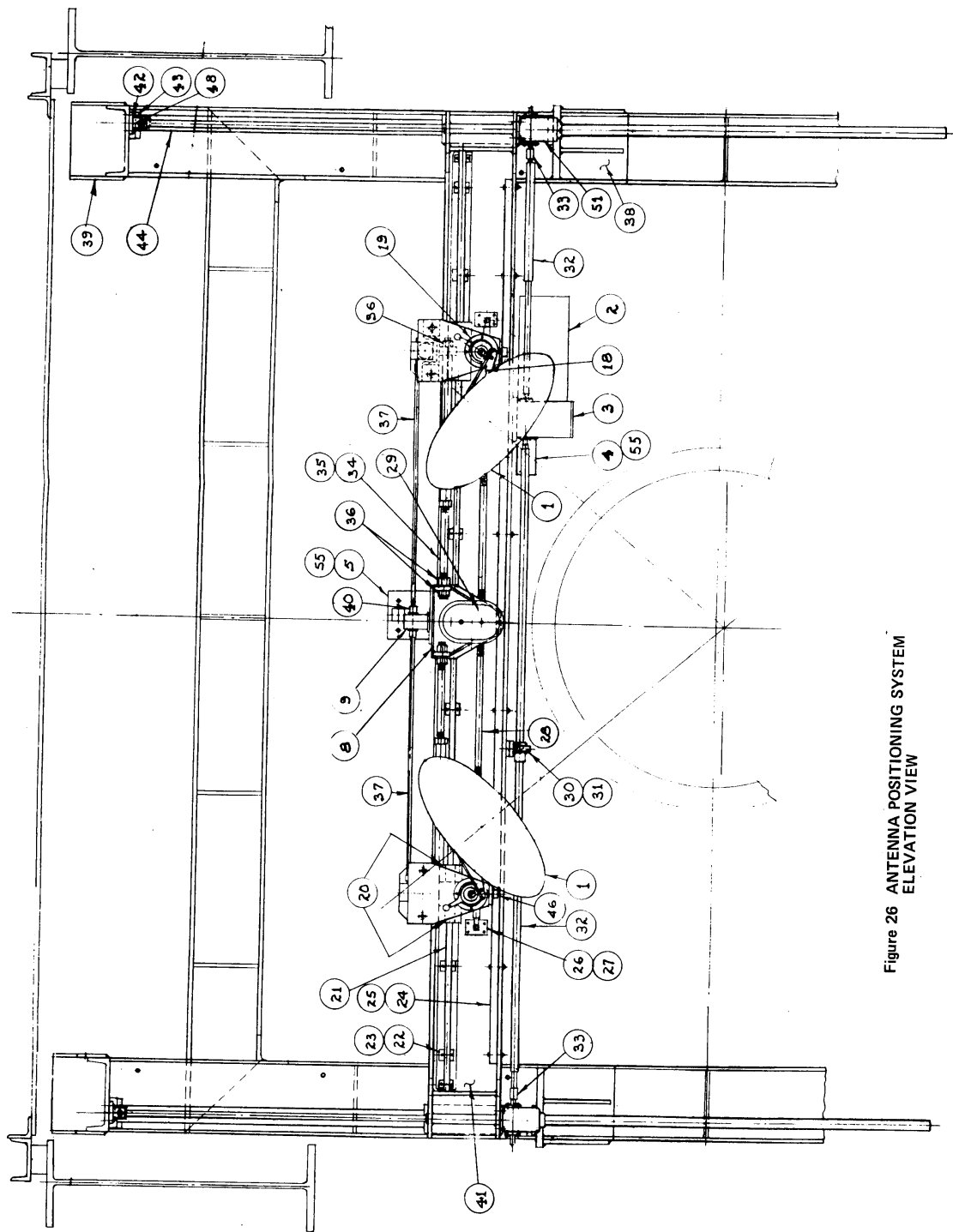


Figure 26 ANTENNA POSITIONING SYSTEM
ELEVATION VIEW

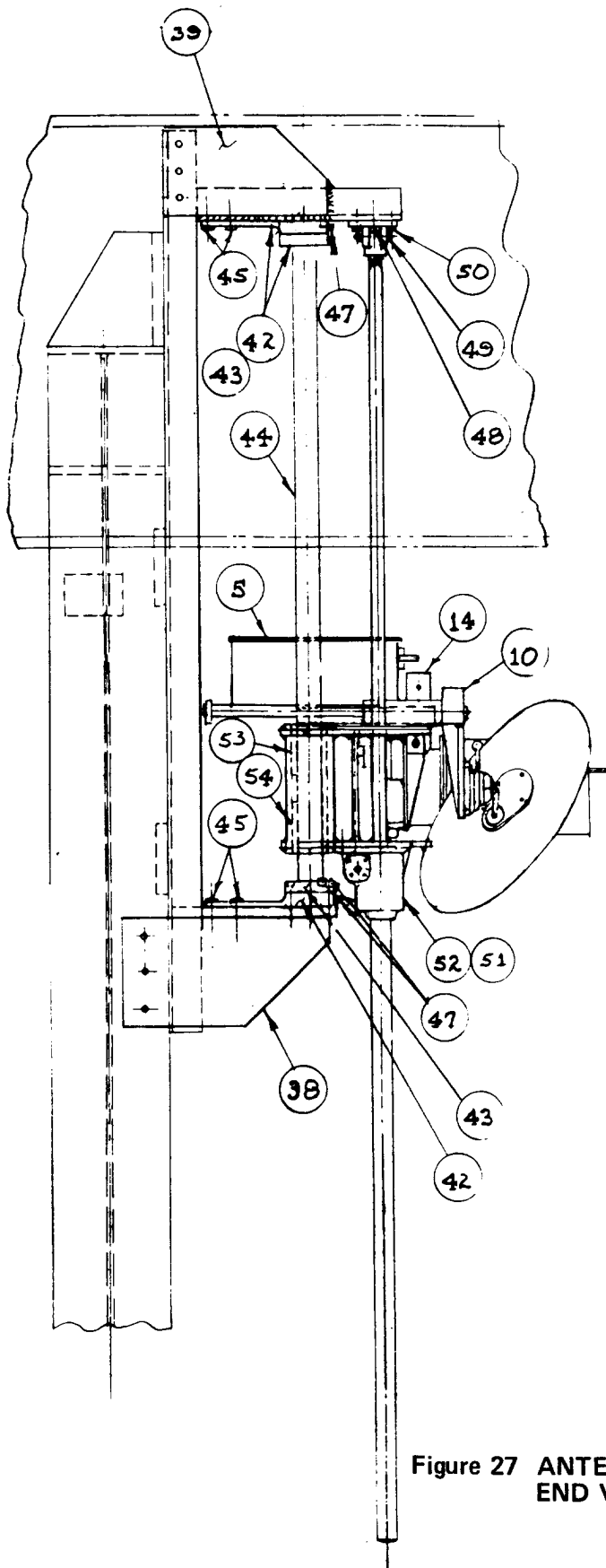


Figure 27 ANTENNA POSITIONING SYSTEM
END VIEW

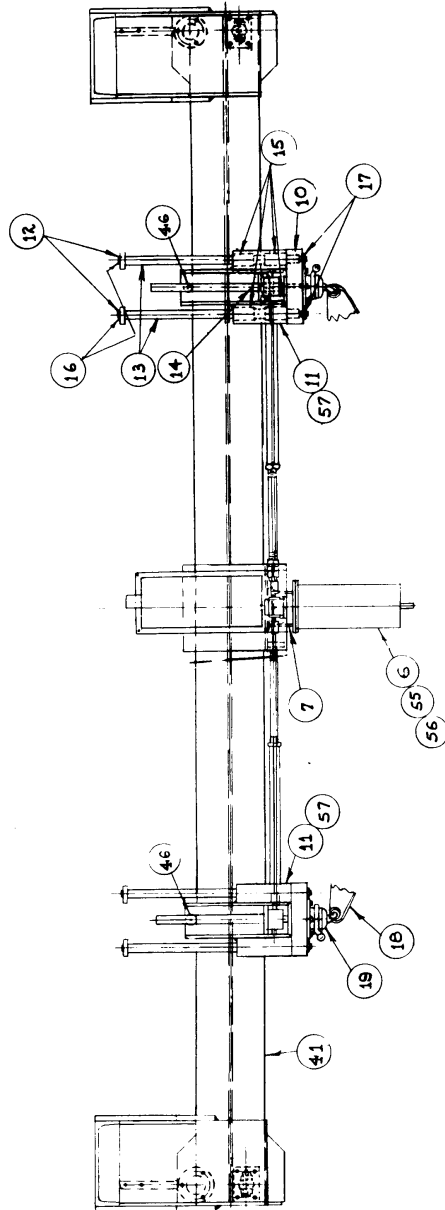


Figure 28 ANTENNA POSITIONING SYSTEM
PLAN VIEW

Permanent magnet-type motors are used in the servo drives. The vertical axis drive consists of a 1-hp motor and a servo amplifier capable of delivering 750 watts. The lateral and axial axes use 1/8-hp motors and 100-W servo amplifiers.

5.1.1 Axial Servo Drive Assembly

The motor, gear train, feedback and position read-out potentiometers are located within Item 5 shown in Figure 26. The 1:1 ratio mitre gear box (Item 9, Figure 27) couples the servo motor rotation with the two axial machine screw jacks (Item 14, Figure 28), moving both antennas simultaneously.

5.1.2 Lateral Servo Drive Assembly

The servo motor, gear train, feedback and position read-out potentiometers are located within Item 6 shown in Figure 28. The rotation of the lateral servo motor is coupled through the gear train directly to a machine screw jack (Item 29, Figure 26), providing linear motion to the two antenna carriages (Items 11, Figure 28) and one central carriage (Item 8, Figure 26).

5.1.3 Vertical Servo Drive Assembly

The one-horsepower servo motor, gear box, feedback and position read-out potentiometers are located within Items 2, 3, and 4 shown in Figure 26. The motor and gear train assembly are coupled to a pair of ball screw jacks (Item 51, Figure 26) which move the main support beam (Item 41, Figure 28).

5.1.4 Antenna Positioners

The microwave antennas (Items 7, Figure 26) are mounted on traveler weldments (Item 10, Figure 27) with commercial work positioners (Item 19, Figure 26). The work positioner consists of a universal-type ball joint which can be locked and unlocked by a control handle. With the positioner unlocked, the antennas can be adjusted as required to obtain the desired pointing directions.

5.2 FUNCTIONAL DESCRIPTION OF THE SERVO SYSTEM

All three servo systems are similar but differ in power level and details of gearing. The schematic and wiring diagrams of the axial, the lateral and the vertical servo channels are shown in Figures 29, 30, and 31, respectively. The functional description of the axial servo system (Figure 29) is also valid for the lateral and vertical channels.

A 10-turn set-point potentiometer P1 is used to set the desired position. (Figure 29). This potentiometer is mounted on the control panel. A similar potentiometer P2 (servo potentiometer) is mechanically connected via precision gearing to the servo motor, and is electrically connected in a bridge circuit with the set-point potentiometer. Power is supplied to the bridge circuit by a +15-V power supply PS1. If the angular positions of the two potentiometers are not the same, an electrical signal is present at the input of the servo amplifier A2. This signal is amplified and applied via diodes D1, D2, relay contacts of RL1 and RL2, and circuit breaker CB1 to the armature of servo motor M1, which drives the shaft of potentiometer P2 in a direction to reduce the error signal to zero. The motor is connected via power gearing to the lead screw and jacks which drive the load.

The servo drive is protected from overtravel in either direction by the mechanically actuated limit switches S1 and S2. With both limit switches closed, relays RL1 and RL2 are energized and current can flow through the diodes and the relay contacts to the motor in both directions. With one of the limit switches open, one of the relays is deenergized and current flow through the motor is restricted through one of the diodes and one pair of relay contacts. The polarity of the diode remaining in the closed circuit will permit only current to flow in a direction which turns the motor opposite to that causing the overtravel. The servo drive can thus be brought back from the limit switch position but cannot be operated beyond this position. Indicator lights L1 and L2, mounted on the positioning control panel, are activated by the respective relays and indicate which travel limit is being exceeded.

Switch S4, shown mounted in the test cabin and common to all three servo systems, when opened will cause power to all servo motors to be switched off. This safety switch can be used by personnel working in the test cabin area to stop all servo action.

The circuit breaker CB1 protects the motor against excessive current. Mounted on the control panel, it can also be used to manually switch off the motor current.

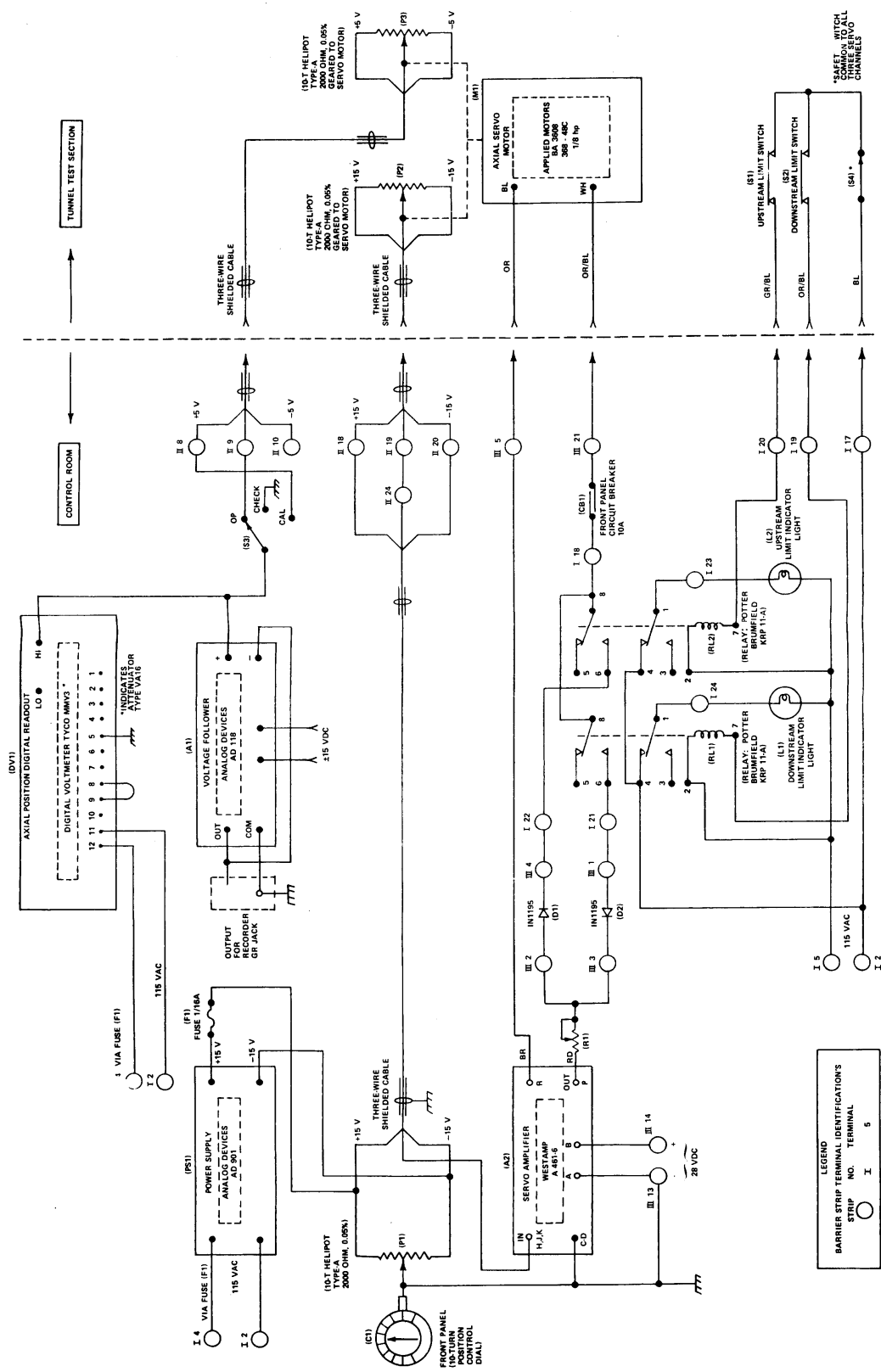


Figure 29 SCHEMATIC AND WIRING DIAGRAM OF AXIAL SERVO CHANNEL

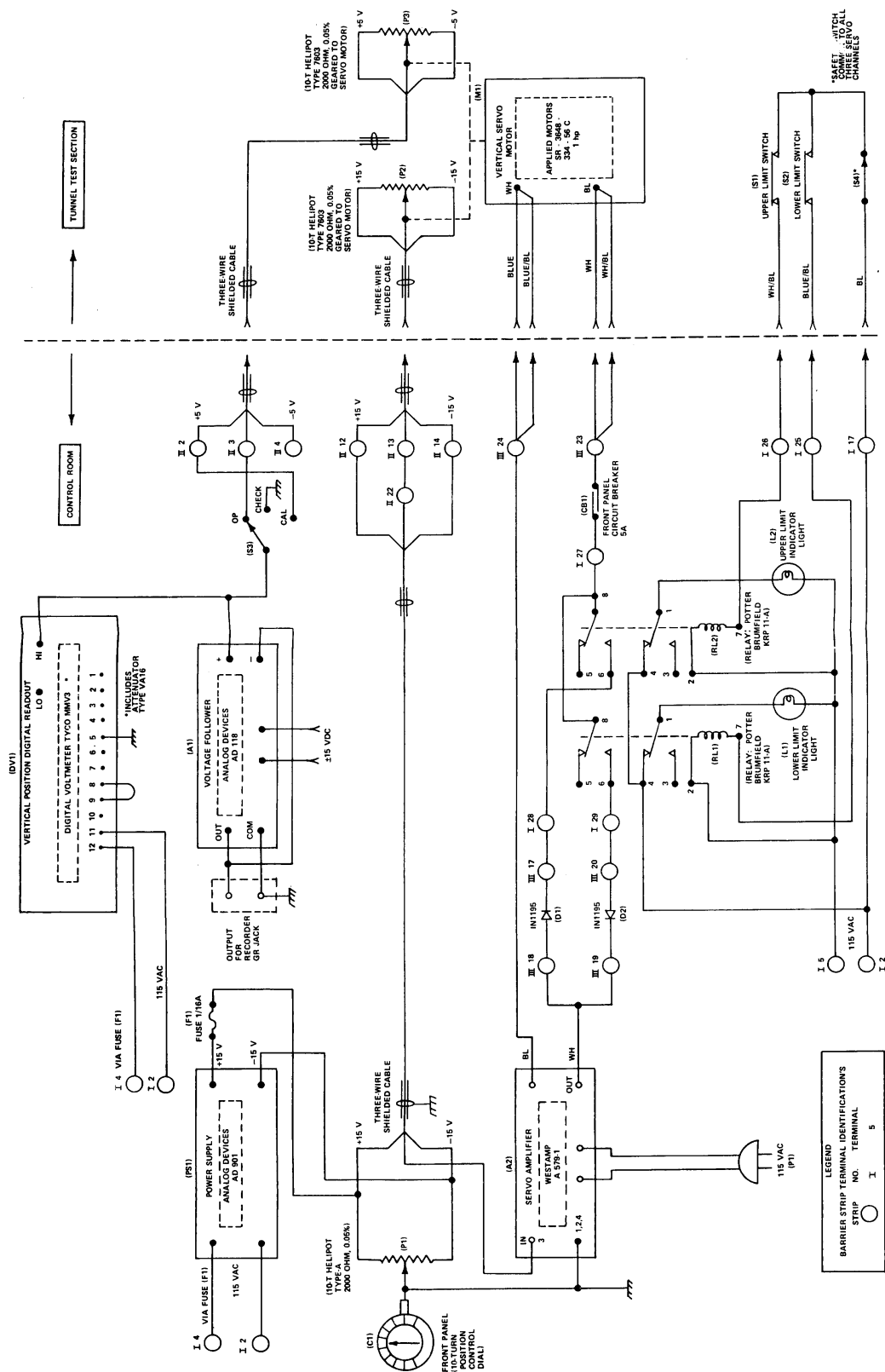


Figure 31 SCHEMATIC AND WIRING DIAGRAM OF VERTICAL AXIS SERVO CHANNEL

A read-out potentiometer P3 is mounted on the same shaft as the servo potentiometer P2. This potentiometer is connected across a regulated +5-volt power supply, and its arm feeds a digital voltmeter. Potentiometers are calibrated at one turn = 10 inches of antenna travel. Accordingly, the output of the read-out potentiometer is scaled at 1 volt per 10 inches. Position is indicated by the digital meter on the control panel to the nearest 0.1 inch. The read-out potentiometer output voltage is also fed through a unity gain isolation (voltage follower) amplifier A1 to an output connector.

5.3 POWER DISTRIBUTION FOR ANTENNA POSITIONING SYSTEM

Electrical power for operation of the servo system is distributed as shown in Figure 32. With pushbutton switch S1 closed, power is applied via relay RL1 contacts to the digital position read-out panel meters and to all ± 15 volt power supplies in the servo control system. All read-out controls are activated and position of the antenna system can be read out on the digital panel meters.

Closing of key switch S2 applies power to relay RL2, and in turn to the internal 115-V outlets O1 and O2. These outlets provide power for the vertical servo amplifier A2 of Figure 31, the 28-volt DC power supply PS1, and blowers B1 and B2. The axial servo amplifier (A2, Figure 29) and the lateral servo amplifier (A2, Figure 30) are fed from the 28-V supply. The blowers provide cooling air for the axial and lateral servo amplifiers.

A green light (L1) located on the control panel indicates that switch S1 is in the "ON" position; a red light (L2) indicates that the motor key switch S2 is in the "ON" position.

Power supply PS2 provides ± 15 volts for the operational amplifiers and voltage followers. Operational amplifier A1 provides the +5.0-volt reference for the position read-out potentiometers. Potentiometer R1 is used to trim the output voltage of A1 exactly to 5.0 volt ± 5 mV. Operational amplifier A2, in an inverting mode, provides -5.0 volt reference for the position read-out potentiometers. Potentiometer R3 is used to trim the -5.0 volt output to within ± 5 mV accuracy.



Section VI

MECHANICAL INSTALLATION

Directions for installation of the antenna positioning system in the test cabin appear in Appendix III. Cooling of the electrical equipment, protection of electrical wiring, and installation of safety switch in the test cabin are discussed in this section.

6.1 COOLING OF EQUIPMENT

The transmitter package (Item 58, Figure 26) and the three servo motor enclosures (Item 5, Figure 26; Item 6, Figure 28; Items 2, 3, and 4, Figure 26) are cooled by circulating air through the enclosures. The air flow supply diagram recommended for implementation of the cooling system is shown in Figure 33. The pressurized air is directed through a globe valve to the transmitter package and through a solenoid valve and globe valve combination to the remainder of the system. These valves should be adjusted such that a flow of approximately 5 cubic feet per minute is attained through the transmitter package, and 15 cubic feet per minute through the rest of the system. The heated air is exhausted to the outside of the tunnel. Two separate air exhaust lines are used.

The servo motor enclosures need air only during actual operation of the servo system. Solenoid valves in both the supply and exhaust lines of this loop permit air to be turned on and off with servo system operation and prevent air leakage from these packages during the test cabin pump-down phase. The transmitter package, which has been designed for minimal air leakage, must be kept under atmospheric pressure at all times.

6.2 PROTECTION OF WIRING

It is recommended that all signal, power and control wiring be covered with heat-resistant asbestos shielding to insure adequate protection from the hot gases during periods of unstabilized flow conditions.

6.3 SAFETY SWITCH INSTALLATION

It is recommended that a safety switch be installed in the test cabin for use in switching off all power to the servo drives. This switch is discussed in Section 5.2. Shown as S4 in Figures 29, 30,

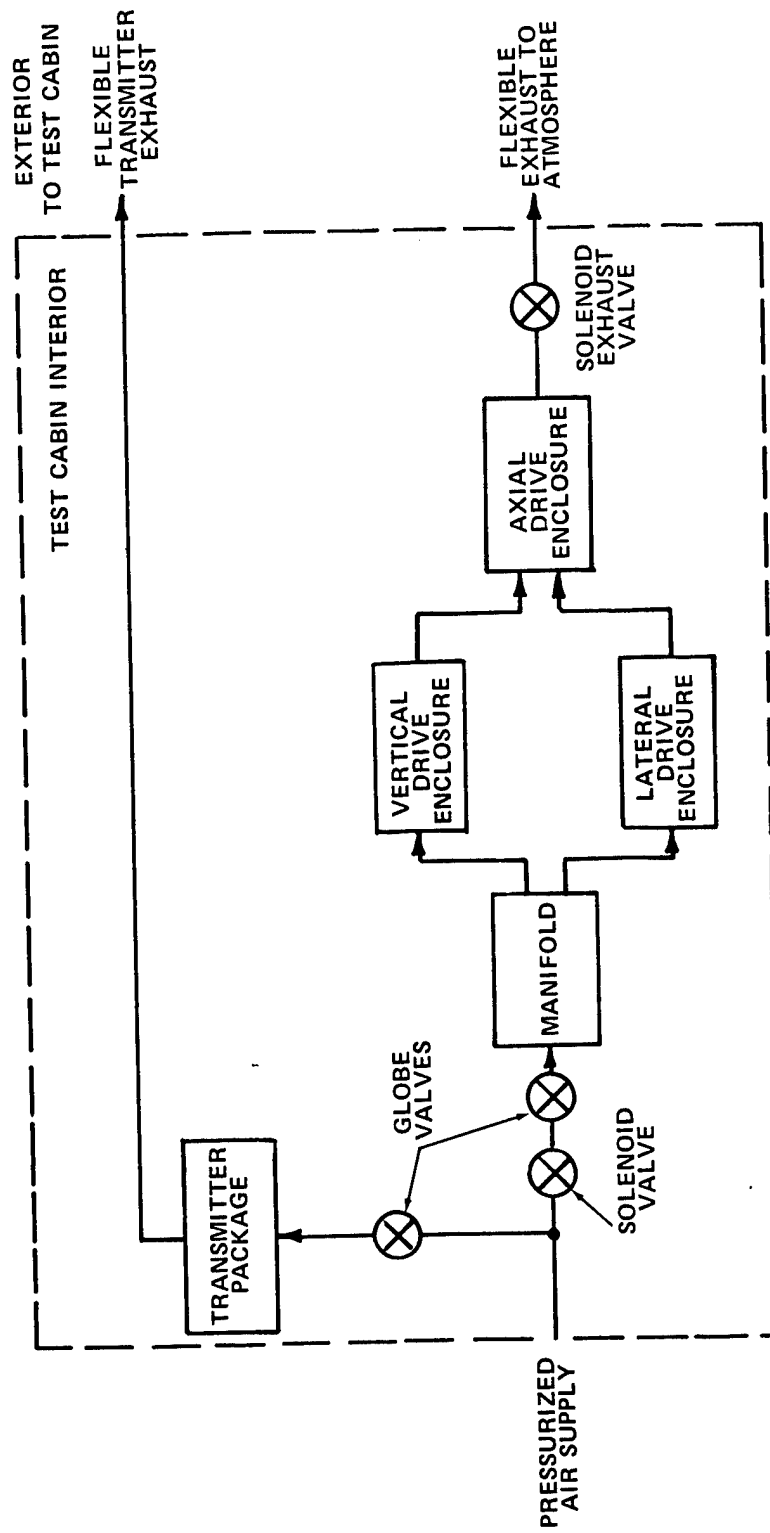


Figure 33 AIR FLOW DIAGRAM

and 31, it is common to all three servo channels. With the switch in the open position, the power to all three servo motors is interrupted through action of relays. In this condition, the servo drives cannot be operated from the servo control panel.

Section VII

ANTENNA POSITIONING SYSTEM OPERATING INSTRUCTIONS

The antenna positioning system is controlled from a panel located in the main control room adjacent to the test cabin. A picture of this panel appears in Figure 34 with titles identifying important control and display functions. The 120-volt 60-cycle primary power is controlled by a combination switch-light. The motor key lock switch and a secondary tunnel safety switch (subsection paragraph 6.3) control the power to all three motors in the servo positioning system. The system cannot be operated if either of these switches is in the off condition.

7.1 SERVO CONTROL PANEL

7.1.1 Digital Indicators

There are four digital indicators on the servo control panel. Three of these indicators are used to monitor the vertical, lateral and axial positions, while the fourth is used to indicate stream velocity. The three position indicators are each equipped with a three-position switch used for calibration of that particular axis. The switch position does not affect servo operation. The switch positions are marked on the panel as operation (OP), checkout (CHK) and calibration (CAL). In the CAL position, the digital indicator monitors the system reference voltage (5.0 V DC). The CHK position of the indicator mode switch is used to check out the operation of the digital indicator with a zero-voltage input. In the OP position, the digital read-out is connected directly to the position potentiometer associated with that particular axis.

The flow velocity indicator is connected with the radar and displays the measured doppler velocity. The velocity is read in kilo-feet per second when properly calibrated (subsection 4.4.2).

7.1.2 Axis Positioning Controls

The axis positioning control knob for each of the three axes is located on the right side of its particular digital indicator. These knobs drive their related ten-turn servo position set-point potentiometers over the specified range of travel. A special set of limit

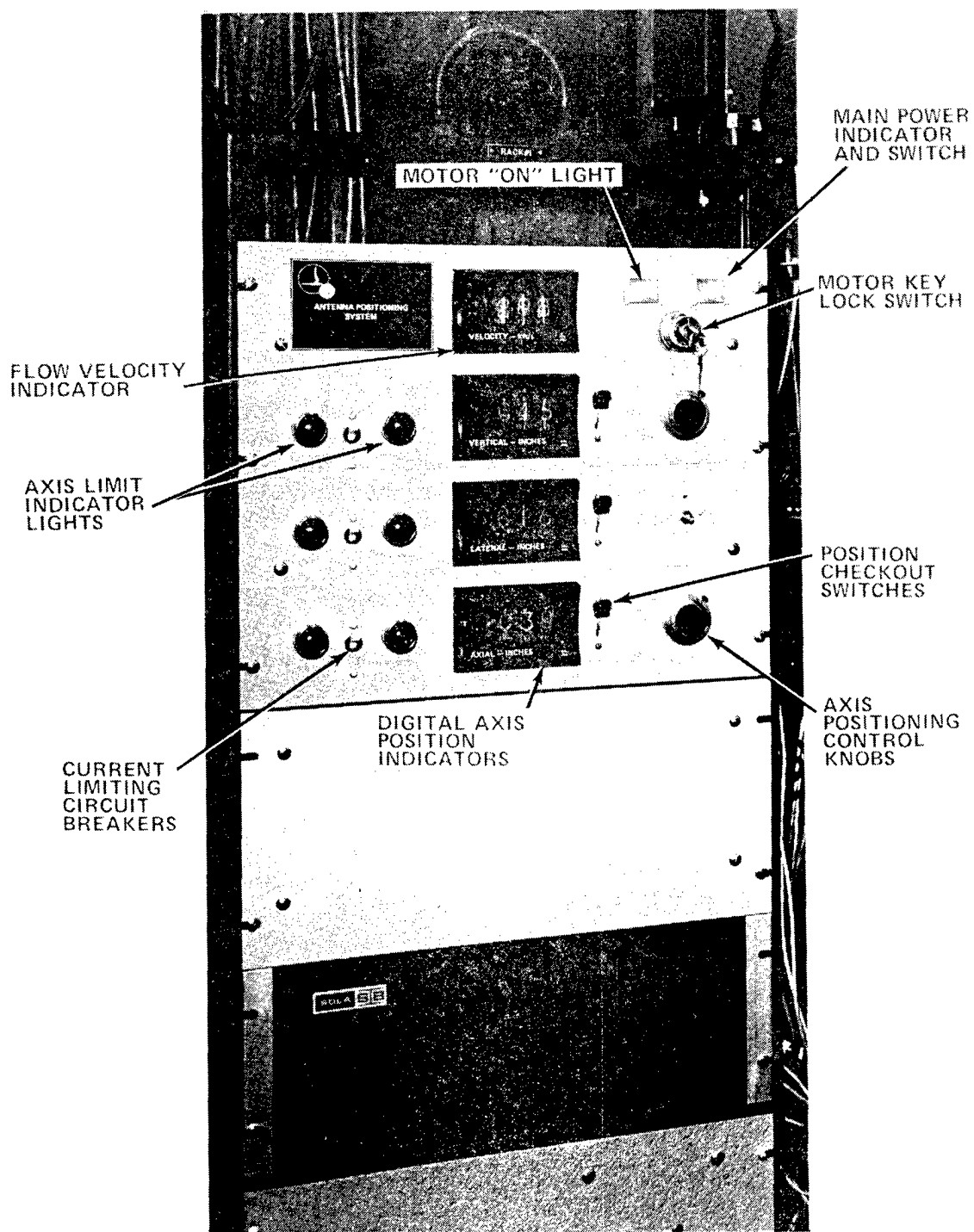


Figure 34 ANTENNA POSITIONING SYSTEM CONTROL PANEL

washers, installed on each of the potentiometer shafts, controls the physical range of positions over which each of these set-point potentiometers can be positioned via the knob. The present limits in travel are set at ± 21 inches for the lateral axis; $+12$ inches to 0.0 inch for the axial axis; and $+21$ inches to -1.0 inch for the vertical axis. The smallest division on the position control knobs is equivalent to 0.1 -inch system travel, with a setting accuracy of ± 0.05 inch. The small lever, part of the knob structure, is used to lock in a desired axis position.

7.1.3 Circuit Breakers

The servo motors used in the antenna positioning system are each protected by a current-limiting circuit breaker-switch combination. These switches, connected in series with each of the motors, remove the driving voltage when excess current through the circuit is sensed. They can also be used to prevent operation of any or all of the servo motors.

7.1.4 Axis Limit Indicator Lights

The axis limit indicator lights appearing on the left side of the individual digital axis position indicators turn red when the limit denoted below the activated light has been exceeded. Both indicators will light when the safety switch in the tunnel test cabin is open (subsection 5.2).

Section VIII
ALIGNMENT, CALIBRATION AND CHECKOUT
OF ANTENNA POSITIONING SYSTEM

8.1 MECHANICAL ZERO POSITIONS

The mechanical "zero" positions of the three axes are as follows:

- (1) Axial Channel: Point of contact between limit switch and limit switch push rod with carriage in upstream position.
- (2) Lateral Channel: Scribe mark on machined lower front edge of main support beam aligned with scribe mark on central carriage.
- (3) Vertical Channel: One inch above the point of contact between the lower limit switch and the limit switch push rod.

8.2 CALIBRATION OF DIGITAL POSITION READ-OUT

Connect an external digital voltmeter of $\pm 0.05\%$ accuracy to the output terminal of amplifier A1, Figure 32. Adjust the trimming potentiometer R1 at the input of the amplifier to obtain an output of $+5.0 \pm 0.005$ volt. With the voltmeter connected to the output of terminal of amplifier A2, Figures 32, adjust R3, for an output of -5.0 ± 0.005 volt.

Set the position checkout switches on the control panel, Figure 34, in the "CAL" position, and adjust the calibration screws, reached through holes in the front panel of the digital indicators, until a read-out of 50.0 inches is obtained. Next, check the zero read-out by setting all position checkout switches to "CHK". The digital read-outs should all read within ± 0.1 inch of zero. The digital read-outs do not have zero adjustments; this step is only to check for correct operation. After this alignment, switch the position checkout switches to "OP" which is the normal operating position.

8.3 SERVO ALIGNMENT

To align the electrical servo system with the mechanical system, it is required that the three axes first be placed at their respective mechanical "zero" positions given in subsection 8.1. The servos can first be used to move the system close to, or coincident with the zero positions. Final adjustments can then be made by manually rotating the servo motor drive shafts after the servo system has been disabled by tripping the motor circuit breakers on the control panel.

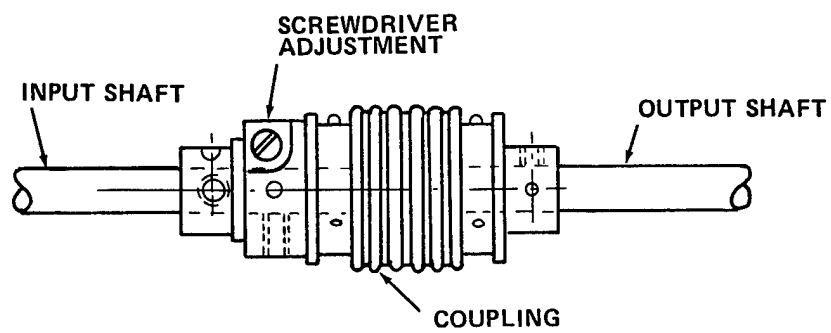
With the system at the mechanical zero position, all position indicators on the control panel should read 0.0 ± 0.1 inch. The coupling between the dual in-line servo potentiometer and the servo motor must be adjusted for each channel that does not give zero indication read-out. To reach the potentiometers and the servo motors, the covers of the servo drive enclosures must be removed. For the axial and lateral channels, phasing of the servo potentiometers is accomplished by turning the screwdriver adjustment of the servo potentiometer coupling shown in Figure 35. For adjustment of the vertical channel servo potentiometers, the three servo clamps holding the dual potentiometer to the mounting flange must be loosened. The potentiometer body then can be rotated to adjust the phasing for zero read-out on the digital indicator. The servo clamps must be tightened after the adjustment.

8.4 ALIGNMENT OF SET-POINT POTENTIOMETERS

With the mechanical axes at their zero positions, the digital read-outs at zero, and the servos disabled by the front panel circuit breakers as described in subsection 8.3, each axis set-point potentiometer is aligned as follows: Connect a DC voltmeter with a range of ± 100.0 volts across the corresponding axis servo amplifier output and adjust the set-point potentiometer with the control knob on the control panel for minimum voltage at the amplifier output. This is a critical adjustment since a few degrees of rotation of the control knob will result in amplifier saturation. If the set-point dial does not read zero when the amplifier output is minimum, loosen the two set screws holding the knob and adjust for zero dial reading. Tighten the set screws after adjusting.

8.5 MECHANICAL ALIGNMENT

Each of the axes should be slewed through its complete range with an observer within the tunnel to check the condition of the mechanical mechanisms (i.e. for smoothness of motion). All set screws



/ Figure 35 SERVO POTENTIOMETER COUPLING FOR AXIAL
AND LATERAL CHANNELS

and shaft couplings used in the axial and vertical drive shafts should be checked to insure proper alignment between axes. A differential displacement between the drive pinions of the left and right ball screw jacks will cause one end of the beam to be lower than the other with the possibility of increased friction and reduced vertical axis operating efficiency.

8.6 POSITION OUTPUTS

Voltage outputs proportional to antenna displacement are provided for each of the axes. These outputs are available at "GR" type jacks on the servo control chassis. The output scaling is 1 volt per 10 inches of displacement.

Section IX
MAINTENANCE AND INSPECTION PROCEDURES

The following maintenance and inspection procedures should be carried out on a monthly basis or as required by usage of the system.

9.1 TRANSMITTER PACKAGE (Figure 6)

Replace blower B1 after 1500 hours of operation.

9.2 WAVEGUIDE

Check all waveguide hardware monthly for loosened connections, or fractures.

9.3 GUIDE ROD MAINTENANCE

The guide rods of the mechanical mechanisms should be cleaned and lubricated with a good grade 20 W motor oil on a 6-month basis. The rods and bearing seals must be wiped free of all dirt-laden oil and a clean fresh oil-soaked cloth used to lubricate the guide rod surface.

9.4 MACHINE SCREW JACKS

The machine screw jacks and their associated lead screws must be lubricated with a low volatile grease (Molybdenum Disulphide) on a 6-month basis. The grease and grease-dirt buildup must be removed from the lead screw using clean absorbent wipers. The system should be exercised after lubrication and any extra grease removed from the jack screw body.

9.5 VERTICAL AXIS DRIVE SHAFT PILLOW BLOCK

The pillow block (Item 30, Figure 26) should be lubricated with low volatility grease every 6 months and the excess grease wiped away.

9.6 AXIAL AXIS MITRE GEAR BOX

The mitre gear box (Item 9, Figure 5) located on the central carriage must be lubricated with a low volatile grease every 6 months, with the excess grease wiped away.

9.7 SERVO MOTORS

The DC servo motors should be inspected after 5000 hours of operation and brushes replaced if necessary.

9.8 SERVO AMPLIFIER COOLING (Figure 32)

The fans cooling these lateral and axial amplifier packages must be checked once every year.

9.9 WIRING HARNESS INSPECTION

The wiring harness and individual cables located in the test cabin should be periodically inspected after runs to determine any deterioration or damage, to the insulation.

Section X
REFERENCES

1. H.W. Prinsen and B.R. Tripp, "Investigation of the Feasibility of a Doppler Radar Technique to Measure Free Stream Velocity in the AFFDL Electrogasdynamics Facility," Report AFFDL-TR-68-78, May 1968.
2. "Instruction Manual", FEL 130A Series, Synchronizer, Frequency Engineering Laboratories, Farmingdale, New Jersey.
3. "Instruction Manual", Microwave Tube Power Supply. Module type FD-00-CV-BV, Micropower Inc., Long Island City, New York.
4. "Instruction Manual", Frequency Meter and Discriminator Type 1142-A, General Radio Company, West Concord, Massachusetts.
5. H.W. Prinsen, R.H. Jarvis, S.N. Margolis, B.R. Tripp, "An Experimental Doppler Radar and Antenna Positioning System for the AFFDL Electrogasdynamics Facility," Report AFFDL-TR-71-100, 1971

Appendix I
RADAR PARTS LISTS

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
MAIN RADAR SUBASSEMBLIES (Figure 4)		
AT1, AT2	Antenna, TRG-A 893-24	Control Data Corporation
IS1	Isolator, MA8P93	Microwave Associates
CP1	Coupler, 20-dB, HP R752A	Hewlett Packard
TR1	Transmitter Package	CAL
PS1	Klystron Power Supply D-FD-00-C4-BV	Midrodod
SN1	Synchronizer FEL 130-A	Frequency Engineering Laboratories
PR1	Radar Signal Processor	CAL
RC1	Mixer-Preamplifier	CAL
F1, F2	Flexible Waveguide BN 207	Airtron
TRANSMITTER PACKAGE (Figure 5)		
W1	Waveguide Hermetic Seal, MA-1334	Microwave Associates
M1	Coupler, 20-dB, HPR752A	Hewlett Packard Palo Alto, Calif.
Q1	Klystron, VA313	Varian
D1, D2	Diode 1N2484	General Electric
D3, D4	Diode Zener U2 815	Unitrode
B1	Blower, Rotron Whisper Fan	Rotron
M1	Thermistor, GB 34 P2	Fenwal
M2	Thermostat, TS 15	Budd
U1-U5	Modules A11, A10, A3, A12 A2 of FEL Synchronizer 130-A	Frequency Engineering Laboratories
U6	27-MHz Line Driver	CAL

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
	27-MHz LINE DRIVER (Figure 10)	
C1, C2, C3	Capacitor 0.01 μ F ceramic	--
C4	Capacitor 50-pF mica	--
R1	Resistor 100 1/4 W 5% composition	--
R2	Resistor 10k 1/4 W 5% composition	--
R3	Resistor 33k 1/4 W 5% composition	--
R4	Resistor 1k 1/4 W 5% composition	--
L1	Coil 1 μ H	--
	TEMPERATURE SAFETY CONTROL UNIT (Figure 7)	
C1, C2	Capacitor 1.0- μ F paper	--
C3	Capacitor 20 μ F tantalitic 15 V	--
R1, R4	Resistor 5 k Variable RH 502U	Allen Bradley
R2	Resistor 22 k 1 W 10% composition	--
R3	Resistor 4.7 k 1/4 W 5% composition	--
R5	Resistor 10 k 1 W 10% composition	--
R7, R8, R9	Resistor 15 k 1/4 W 5% composition	--
R10	Resistor 100 k 1/4 W 5% composition	--
R11	Resistor 1 k 2 W 10% composition	--
Q1	Transistor 2N697	Fairchild
D1	Diode 1N914	Transitron
A1	Operational Amplifier LM 307	National Semiconductor
A2	Voltage Comparator LM 306	National Semiconductor
PS1	Power Supply \pm 15 V PM552	Computer Products
RL1	Relay 41-F-1000 S-Sil	Sigma

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
	RADAR SIGNAL PROCESSOR (Figure 16)	
PS1, PS2	Power Supply 12 V, Model M12. 0-0.2	Technipower
M1, M2	Meter 0-50 micro-A, Model 1329	Simpson
A1	Main Doppler Amplifier	CAL
A2	Frequency Meter, Type 1142-A	General Radio
A3	Detector and Schmitt Trigger	CAL
A4	Velocity Gating and Holding Circuit	CAL
R1	Resistor 5 k, Variable Model A	Helipot
	MAIN DOPPLER AMPLIFIER (Figure 17)	
R1, R6	Resistor 56 1/4 W 5% composition	--
R2, R3, R8 R9, R14, R15	Resistor 27 1/4 W 5% composition	--
R4	Resistor 2.2 k 1/4 W 5% composition	--
R5	Resistor 1 k Variable RH 102U	Allen Bradley
R7, R12, R13, R16	Resistor 5.6 k 1/4 W 5% composition	--
R10, R11, R17 R18, R19, R21 R24	Resistor 1 k 1/4 W 5% composition	--
R20, R23	Resistor 100 1/4 W 5% composition	--
C1	Capacitor 50 pF mica	--
C2, C9, C10	Capacitor 0.1 μ F ceramic	--
C3	Capacitor 100 pF mica	--
Q1, Q2, A3, Q4, Q5, Q6, Q7, Q8	Transistor 2N3391	General Electric
C4	Capacitor 300 pF mica	--
C5	Capacitor 1000 pF ceramic	--
C6, C8	Capacitor 0.01 μ F ceramic	--

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
C7	Capacitor 200 pF mica	--
C11, C12 C13, C14	Capacitor 1 μ F tantalytic 15V	--
L1, L2	Inductor 0.2 mH, molded	--
DETECTOR AND SCHMITT TRIGGER (Figure 19)		
R1, R4	Resistor 1 k 1/4 W 5% composition	--
R2, R6, R19, R24	Resistor 4.7 k 1/4 W 5% composition	--
R3	Resistor 470 1/4 W 5% composition	--
R5, R12 R15	Resistor 1.5 k 1/4 W 5% composition	--
R7, R8, R21	Resistor 2.2 k 1/4 W 5% composition	--
R9, R10, R13	Resistor 100 k 1/4 W 5% composition	--
R11	Resistor 100 k variable RK 104U	Allen Bradley
R14	Resistor 220 k 1/4 W 5% composition	--
R16	Resistor 560 1/4 W 5% composition	--
R17	Resistor 2.7 1/4 W 5% composition	--
R18	Resistor 5 k Variable RH502U	Allen Bradley
R20, R22	Resistor 10 k 1/4 W 5% composition	--
R23	Resistor 3.3 k 1/4 W 5% composition	--
L1	Inductor 2 mH molded	--
L2, L3	Inductor 0.2 mH molded	--
C1	Capacitor 0.1 μ F ceramic	--
C2	Capacitor 1000 pF mica	--
C3	Capacitor 2000 pF mica	--
C4, C7, C9	Capacitor 500 pF mica	--
C5	Capacitor 5000 pF ceramic	--
C6, C8	Capacitor 0.2 μ F metallized mylar	--
C10, C11 C12, C13	Capacitor 1.0 μ F tantalytic 15 V	--

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
D1, D3	Diode 1N914	Transitron
D2	Diode Zener 1N752	Motorola
Q1, Q2	Transistor 2N3906	Motorola
Q3	Transistor 2N3291	General Electric
A1, A3, A4	Operational Amplifier 809 CE	Amelco
A2	Voltage Comparator LM 306	National Semiconductor
	VELOCITY GATING AND HOLDING CIRCUITS (Figure 20)	
R1, R3, R10, R12	Resistor 10 k 1/4 W 5% composition	--
R2	Resistor 8.2 k 1/4 W 5% composition	--
R4, R16	Resistor 330 1/4 W 5% composition	--
R5, R8	Resistor 1 k Variable RH102 U	Allen Bradley
R6	Resistor 4.7 k 1/4 W 5% composition	--
R7	Resistor 100 k 1/4 W 5% composition	--
R9	Resistor 5 k Variable RH502 U	Allen Bradley
R11	Resistor 50 k Variable RH503 U	Allen Bradley
R13	Resistor 3.9 k 1/4 W 5% composition	--
R14	Resistor 1.5 k 1/4 W 5% composition	--
R15	Resistor 2.7 k 1/4 W 5% composition	--
C1	Capacitor 2000 pF mica	--
C2	Capacitor 5000 pF mica	--
C3	Capacitor 500 pF mica	--
C4	Capacitor 50 pF mica	--
C5	Capacitor 10,000 pF mica	--
C6	Capacitor 0.1 μ F metallized mylar	--
C7, C8	Capacitor 100 pF mica	--

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
C9, C10 C11, C12	Capacitor 1.0 μ F tantalytic 15 V	--
L1	Inductor 1 mH molded	--
L2, L3	Inductor 200 μ H molded	--
D1, D2, D3	Diode 1N914	Transitron
Q1	MOSFET 2N4066	Fairchild
Q2	Transistor 2N3906	Motorola
Q3	Transistor 2N706	Fairchild
A1, A3	Operational Amplifier 809CE	Amelco
A2	Operational Amplifier 141A	Analog Devices

Appendix II
SERVO POSITIONING SYSTEM DRAWINGS,
SUBASSEMBLIES, AND PARTS LISTS

II.1 CAL-FABRICATED SUBASSEMBLIES

<u>Drawing No.</u>	<u>Description</u>
H87-0000	Assembly Servo Antenna Positioning
H87-0001A*	Mounting Plate
H87-0002	Traveler
H87-0003A	Carriage
H87-0004A	Carriage Motor Mount
H87-0005A	Main Beam Detail
H87-0006A	Beam Support
H87-0007	Detail-Servo Antenna
H87-0008A	Axial Gear Box "Z" Servo
H87-0009A	Transverse Gear Box "X" Servo
H87-0010A	Vertical Gear Box "Y" Servo
H87-0011A	Enclosure and Gear Assembly
H87-0012	Bracket
H87-0013	Installation Drawing
H87-0014	Rod Support Flexure
H87-0020	Hole Pattern Templates
H87-0030	Traveler Assembly

* A denotes A size print.

II.2 PARTS LIST OF MECHANICAL COMPONENTS

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
1	25	2	Antenna	See Parts List, Appenix I (Main Radar Subassemblies)
2	25	1	Enclosure, Motor H87-0011-5	CAL
3	25	1	Gear Box, Vertical H87-0010-1	CAL
3 ^{**}	25	1	Gear, Spur YA70	Boston Gear
3 ^{**}	25	1	Gear, Spur YA84	Boston Gear
3 ^{**}	25	1	Gear, Spur S-20-40	Sterling
3 ^{**}	25	2	Gear, Spur H21-30-P3	Sterling
3 ^{**}	25	1	Gear, Anti-Backlash Z6D-144-A	Sterling
3 ^{**}	25	1	Gear, Spur P21-36-P2	Sterling
3 ^{**}	25	2	Gear, Anti-Backlash Z6D-150-A	Sterling
3 ^{**}	25	1	Gear, Anti-Backlash Z6L-96-A	Sterling
3 ^{**}	25	6	Ball Bearing FC-4-FMM	MRC
3 ^{**}	25	2	Ball Bearing R-10-ZZ	MRC
3 ^{**} (55)	25	1	Dual Potentiometer	See Parts List Vertical Axis Servo Channel
3 ^{**}	25	1	Motor, DC 1 hp	See Parts List Vertical Axis Servo Channel
3 ^{**}	25	1	Coupling, Flexible T-11-3	PIC Design

^{**} Denotes components which are part of item so marked.

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
4	25	1	Enclosure, Potentiometer H87- 0011-1	CAL
5	25	1	Weldment, Axial Gear Box H87-0088-1	CAL
5 **	25	1	Gear, Spur 48P 0.3750 inch Bore	SECS
5 **	25	1	Gear, Anti-Backlash 48P 0.1250 inch Bore	SECS
5 **	25	1	Speed Reducer 200:1 U2-15	PIC Design
5 ** (55)	25	1	Dual Potentiometer	See Parts List Axial Axis Servo Channel
5 **	25	1	Motor, DC 1/8 hp	See Parts List Axial Axis Servo Channel
6	27	1	Motor Enclosure H87-0009-7	CAL
7	27	1	Gear Box Lateral H87-0009-1	CAL
7 **	27	1	Gear, Spur 48P 0.3750 inch Bore	SECS
7 **	27	1	Gear, Anti-Backlash 48P 0.1250 inch Bore	SECS
7 **	27	1	Speed Reducer 200:1 U2-15	PIC Design
7 ** (55)	27	1	Dual Potentiometer	See Parts List Lateral Axis Servo Channel
7 **	27	1	Motor, DC 1/8 hp	See Parts List Lateral Axis Servo Channel
7 **	27	1	Coupling Flexible T-11-3	PIC Design

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
8	25	1	Central Carriage H87-0004-1	CAL
9	25	1	Gear Box, Mitre Simplex	Templeton, Kenly & Co.
10	27	1	Traveler H87-0002-1	CAL
11	27	2	Carriage, Antenna H87-0003-1	CAL
12	27	4	Stop H87-0007-4	CAL
13	27	4 21 inches long	Shaft 1.0 inch Diameter Ground	Thomson Industries, Inc.
14	26	2	Screw Jack Simplex JM-05	Templeton, Kenly & Co.
15	27	8	Ball Bushing A-162536	Thomson Industries, Inc.
15 ^{**}	27	8	Seals S-1000 used with Item 15	Thomson Industries, Inc.
15 ^{**}	27	8	Retaining Ring N5000-156	Walde's Truarc
16	27	4	Hex HD Cap Screw 1/2"-20"x1" long	Stock
17	27	4	Hex Nut 1/2" - 20"	Stock
18	27	2	Adapter, Antenna H87-0001-1	CAL
19	25	2	Work Positioner 5251A1	McMaster Catalog
20	25	6	Ball Bushing PBO-160 PN	Thomson Industries, Inc.
21	25	130 inches	Shaft 1.0 inch Diameter Ground and Drilled	Thomson Industries, Inc.
22	25	48 inches	Shaft Support Rail	Thomson Industries, Inc.
23	25	24	Socket HD Cap Screw and Nuts 1/4" - 28"x1" long	Stock

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
24	25	1	Bar 1"x1"x122" long	Stock
25	25	11	Socket HD Cap Screw and Nuts 1/4"-20"x2" long	Stock
26	25	2	Bracket, Tie Down H87-0007-6	CAL
27	25	8	Socket HD Cap Screw and Nuts 1/4"-28"x1-1/4" long	Stock
28	25	1	Lead Screw (Part of Item 29)	Templeton, Kenly & Co.
29	25	1	Screw Jack Simplex JM-10	Templeton, Kenly & Co.
30	25	1	Pillow Block 06934-6L	Boston Gear
31	25	2	Socket HD Cap Screw 1/2"-20"x2" long	Stock
32	25	120 inches	Tubing, Steel 1-1/4" O.D. x 5/32" wall	
33	25	2	Coupling FC-12-1/2	Boston Gear
34	25	72 inches	Rod Threaded 3/4"-10"	Stock
35	25	4 feet	Pipe, 1" Diameter	Stock
36	25	8	Hex Nut 3/4"-10"	
37	25	2	Rod, Drill 3/8" x 36" long	Stock
38	26	2 L/R	Support, Main H87-0006-1 and 2	CAL
39	26	2	Support, Upper H87-0006-3	CAL
40	25	4	Coupling CR6-3/8"	Boston Gear
41	27	1	Beam, Main H87-0005-1	CAL
41**	27	12 feet	Beam, "H" 10 WF -39	Stock

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
42	26	4	Support, Flexure Rod H87-0014-1	CAL
43	26	4	Support, Rod H87-0007-5	CAL
44	26	2 58 inches long	Shaft 2.0" Diameter Ground	Thomson Industries, Inc.
45	26	8	Socket HD Cap Screw 3/8"-24"x1" long	Stock
46	27	6	Bearings Camrol CF- 1-1/8	McGill
47	26	8	Socket Set Screw 3/8"-16"x1" long	Stock
48	26	2	Clevis H87-0007-1	CAL
49	26	2	Bolte Nut 5/8"-18"x2-1/2" long	Stock
50	26	8	Socket HD Cap Screw and Nut 1/2"-20"x1-1/2" long	Stock
51	26	2	Ball Screw Jack 2-1/2 BSJ	Philadelphia Gear
52	26	8	Socket HD Cap Screw 3/8"-16"x1" long	Stock
53	26	4	Ball Bushings A-324864	Thomson Industries, Inc.
53**	26	4	Seals S-2000 used with Item 53	Thomson Industries, Inc.
54	26	4	Retaining Rings N5000-300	Walde's Truarc
55	--	-	Potentiometer (see 3(55), 5(55), 7(55))	
56	27	2	Bracket H87-0012-1	CAL
57	27	2	Carriage H87-0030-1	CAL

REFERENCE SYMBOL OR ITEM NO.	FIGURE NO.	QUANTITY	DESCRIPTION	MANUFACTURER
58	25	1	Enclosure, Transmitter	CAL
59	25	1	Isolator, Waveguide	See Parts List Appendix I (Main Radar Subassemblies)
60	25	1	Coupler 20 dB	See Parts List Appendix I (Main Radar Subassemblies)
61	25	2	Waveguide, Flexible	See Parts List Appendix I (Main Radar Subassemblies)

II.3 ELECTRICAL COMPONENTS

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
	AXIAL AXIS SERVO CHANNEL (Figure 29)	
A1	Voltage Follower AD 118	Analog Devices
A2	Servo Amplifier A461-6	Westamp, Inc.
PS1	Power Supply AD901	Analog Devices
DV1	Digital Voltmeter MMV3	TYCO
P1	Potentiometer, 10T, 2000 ohm, Type A	Helipot
P2, P3	Dual Potentiometer, 10T 2000 ohm, Type A	Helipot
M1	Servomotor 1/8 hp BA 3608-368-48C	Applied Motors
RL1, RL2	Relay, KRP 11A	Potter Brumfield
D1, D2	Diode, 1N1195	Motorola
S1, S2	Limit Switch 1LN 1-5-RH(LH)	Microswitch
CB1	Circuit Breaker JAI-B3-5-50-P	Heineman Electric Corp.
C1	Dial 10T, Model RB/C	Helipot
L1, L2	Indicator Lights 51-4001-0111-301	Dialco
R1	Resistor, 3 ohm, adjustable 1156C	Ohmite
S3	Lever Switch, CRL 1452	Central Lab
	LATERAL AXIS SERVO CHANNEL (Figure 30)	
A1	Voltage Follower AD118	Analog Devices
A2	Servo Amplifier A461-6	Westamp, Inc.
PS1	Power Supply AD901	Analog Devices
DV1	Digital Voltmeter MMV3	TYCO

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
P1	Potentiometer, 10T, 2000 ohm Type A	Helipot
P2, P3	Dual Potentiometer, 10T, 2000 ohm, Type A	Helipot
M1	Servo motor 1/8 hp BA 3608-368-48C	Applied Motors
RL1, RL2	Relay, KRP 11A	Potter Brumfield
D1, D2	Diode, 1N1195	Motorola
S1, S2	Limit Switch 2LN1-5-RH(LH)	Microswitch
CB1	Circuit Breaker JAI-B3-5-50-P	Heineman Electric Corp.
C1	Dial 10T, Model RB/C	Helipot
L1, L2	Indicator Lights 51-4001-0111-301	Dialco
R1	Resistor, 3 ohm, adjustable 1156C	Ohmite
S3	Lever Switch CRL 1452	Central Lab
VERTICAL AXIS SERVO CHANNEL (Figure 31)		
A1	Voltage Follower AD118	Analog Devices
A2	Servo Amplifier A579-1	Westamp, Inc.
PS1	Power Supply AD901	Analog Devices
DV1	Digital Voltmeter MMV3	TYCO
P1	Potentiometer, 10T, 2000 ohm, Type A	Helipot
P2, P3	Dual Potentiometer, 10T 2000 ohm, 7603	Helipot
M1	Servo Motor, 1 hp, SR 3648-334-56C	Applied Motors
RL1, RL2	Relay, KRP 11A	Potter Brumfield
D1, D2	Diode, 1N1195	Motorola
S1, S2	Limit Switch 1LN1-5-RH(LH)	Microswitch

REFERENCE SYMBOL OR ITEM NO.	DESCRIPTION	MANUFACTURER
CB1	Circuit Breaker JAI-A310-250-2A	Heineman Electric Corp.
C1	Dial 10T, Model RB/C	Helipot
L1, L2	Indicator Lights 51-4001-0111-301	Dialco
S3	Lever Switch CRL 1452	Central Lab
AC AND DC POWER DISTRIBUTION FOR ANTENNA CONTROL SYSTEM (Figure 32)		
S1	Pushbutton Switch, 14DMI-C2	Microswitch
S2	Switch, Key Model, W250T-15113	Cutler Hammer
PS	Power Supply, 28 volt, 282128	Sola
PS2	Power Supply \pm 15 volt, AD 902	Analog Devices
A1, A2	Operational Amplifier, AD 119A	Analog Devices
R1	Resistor, Variable, 10k, Helitrim	Helipot
R2, R4	Resistor, Metal Film, 100k, 1/4 W, 1%	--
R3	Resistor, Variable, 50k, Helitrim	Helipot
B1, B2	Blower, Cooling Package 1208AE	Wakefield
T1, T2	Transformer 115-6.3V, P-6134 21-F09	Stancor
RL1, RL2	Relay PR11AY	Potter Brumfield

Appendix III
DIRECTIONS FOR THE INSTALLATION OF
THE ANTENNA POSITIONING SYSTEM

III.1 TUNNEL MODIFICATION REQUIRED PRIOR TO THE INSTALLATION OF
THE ANTENNA POSITIONING SYSTEM

- (1) Structural changes to the tunnel support frame (See Drawing #H87-0020)
 - (a) Weldments to the rectangular "I" beam structure surrounding the nozzle.
 - (b) Additional mounting support brackets extending above the two vertical "I" beams at the left and right side of the nozzle.

(2) Mounting Surface

The downstream surfaces of the added structural members discussed in subsection III.1(1) shall be located to within $\pm 1/32$ inch and free of weld splatter or any other irregularities.

(3) Mounting Hole Pattern

- (a) A pair of templates supplied by CAL should be utilized (See Drawing # H87-0020) in the drilling and tapping of the required mounting holes.
- (b) It is recommended that the four centrally located mounting holes, two for each of the antenna support structures, be drilled and tapped, since the configuration prevents the use of standard bolts and nuts unless hand holes are cut through the flange of the beam.

III.2 ANTENNA POSITIONER MOUNTING HOLES

- (1) The templates supplied by CAL shall be clamped in place as indicated in Drawing # H87-0020.
- (2) These templates shall be located, using a transit, such that the dimensions and the horizontal and vertical scribed lines match those indicated by the drawing.

- (3) These templates shall be used to locate the drilled and tapped holes (6 per side) required to hold the antenna positioner supports to the tunnel structure such that the two 2-inch-diameter rods will be vertical, parallel and of the correct spacing. The four additional holes, two on the top and two on the bottom in the left antenna support structure, should be ignored.

III.3 INSTALLATION OF THE ANTENNA POSITIONER WITHIN THE TEST CABIN

- (1) The nozzle of the arc heater should be removed.
- (2) The complete Antenna Positioner System shall be lowered into place and all bolts started several turns into the newly drilled and tapped holes.
- (3) A transit or machinist level shall be used to align the vertical rods (2-inch-diameter) such that they are vertical in all directions and parallel with each other.
- (4) Shim stock shall be used between the tunnel structure and the antenna positioner supports as needed to insure minimum stress in the channel supports.
- (5) All 12 bolts, 6 on each side, should be tightened securely.
- (6) The small beam at the bottom end of the support structure can be removed.
- (7) The lifting structures bolted to the main beam should be removed and stored.
- (8) The nozzle can now be reinstalled.

III.4 CABLING REQUIREMENTS

- (1) A 2-1/2-inch-diameter conduit is suggested to accommodate the servo positioner electrical cables.
- (2) A 2-1/2-inch-diameter conduit is suggested to accommodate the radar signal and power cables.

- (3) Possible positions of these conduits are shown in Drawing # H87-0013 B.
- (4) These conduits should extend through the test cabin wall on the side nearest the console area. A 90° pulling elbow can be used at the outside of the test cabin wall when required.
- (5) Radar signal and power cables, approximately 150 feet long, are supplied with the radar system. It is recommended that these cables run uninterrupted to the radar control panel; however, junction boxes and extension wiring can be used when the cables are too short for this purpose.
- (6) Cabling, 150 feet long, is supplied with the servo control system. It is recommended that the six shielded signal cables run uninterrupted to the servo control console.
- (7) A safety switch (SPST-NC) must be installed in the test cabin. This switch will (when activated) disable and stop the servo drives.

III.5 AIR SUPPLY AND EXHAUST

- (1) The diagnostic radar system requires a clean air supply (oil and moisture filter) with an adjustable pressure range between 20 to 30 lbf/in² and a minimum flow capability of 20 cubic feet per minute.
- (2) An air exhaust should be provided for a 1-1/4-inch-inside-diameter flexible hose which will exhaust the coolant air from the system to the atmosphere.